SEWAGE AND INDUSTRIAL WASTES

JOURNAL of the FEDERATION OF SEWAGE AND INDUSTRIAL WASTES ASSOCIATIONS

Special Features

Overflows from Combined Sewers—Camp

Refinery Wastes—Lewis and Kaplovsky

Sludge Digestion—Keefer

Syndets in Surface Waters—Engelbrecht and Morgan

Automotive Manufacturing Wastes—Milne

Operator's Corner

Job Classifications and Salaries, Plant Maintenance

APRIL 1959—VOL. 31, No. 4

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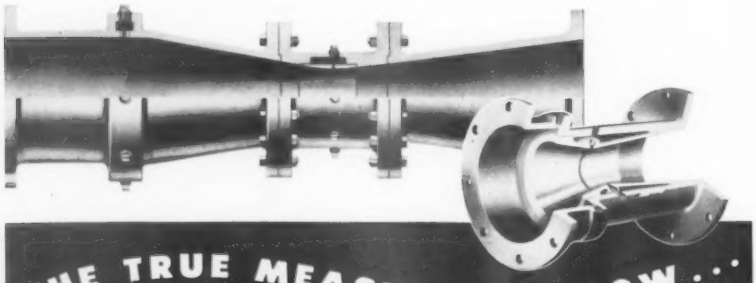

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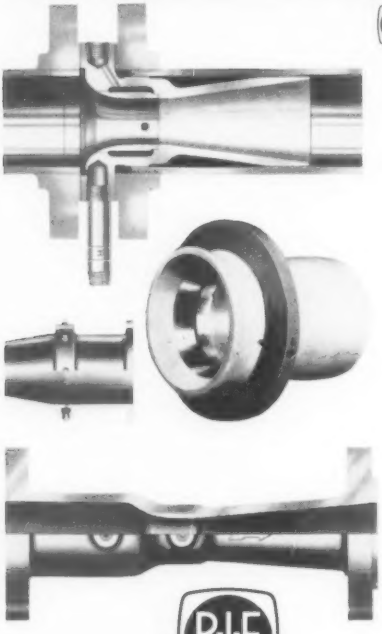

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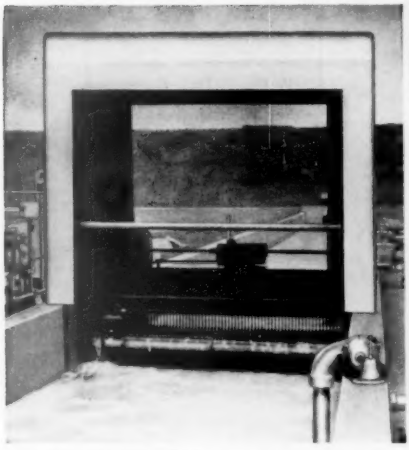

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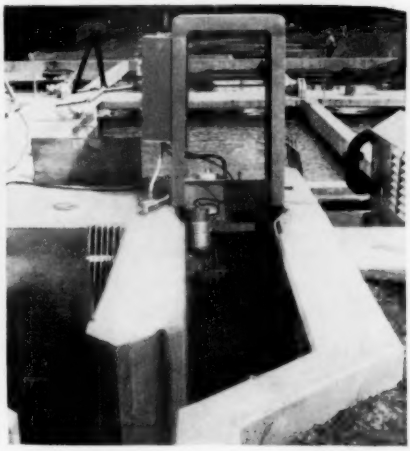

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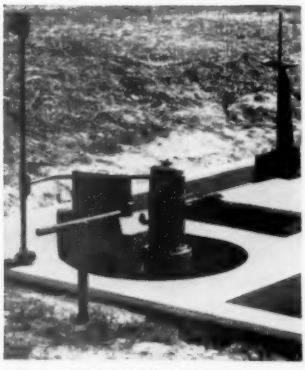

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SEWAGE AND INDUSTRIAL WASTES

Journal of the Federation of Sewage and Industrial Wastes Associations

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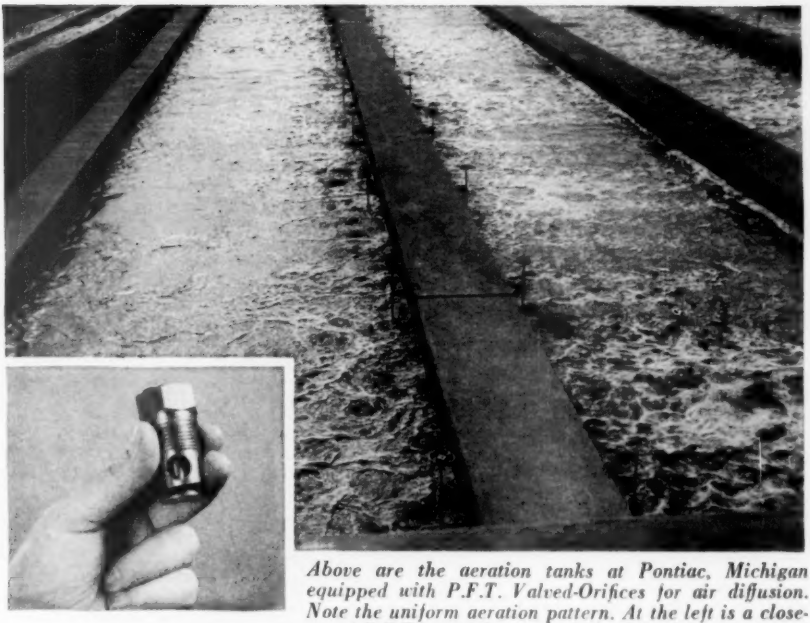

Above are the aeration tanks at Pontiac, Michigan equipped with P.F.T. Valved-Orifices for air diffusion. Note the uniform aeration pattern. At the left is a close-up of P.F.T.'s stainless steel Valved-Orifice.

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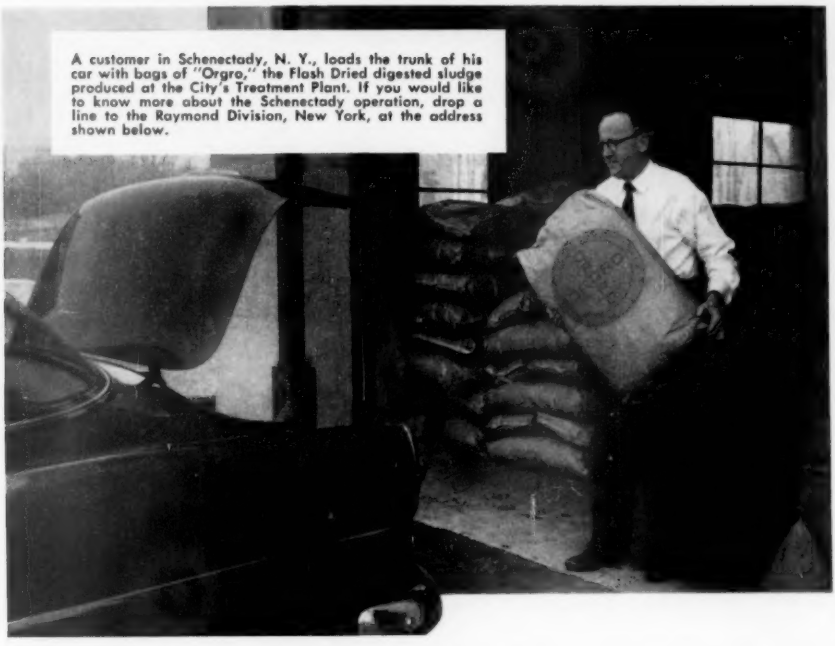

A customer in Schenectady, N. Y., loads the trunk of his car with bags of "Orgro," the Flash Dried digested sludge produced at the City's Treatment Plant. If you would like to know more about the Schenectady operation, drop a line to the Raymond Division, New York, at the address shown below.

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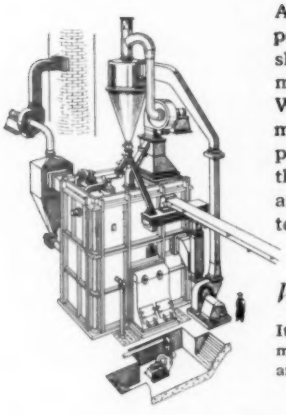

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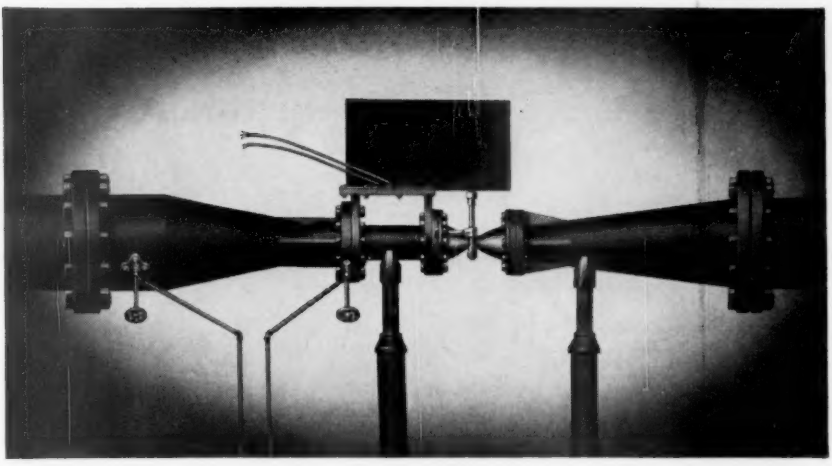

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Association	*Place*	*Time*
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Arizona Sewage and Water Works Assn.	Hi-Way House Hotel Phoenix, Ariz.	Apr. 16–18, 1959
Kansas Sewage and Industrial Wastes Assn. (*Change in Location*)	Besse Hotel Pittsburg, Kans.	Apr. 22–24, 1959
California Sewage and Industrial Wastes Assn.	Lafayette Hotel Long Beach, Calif.	Apr. 29– May 2, 1959
Michigan Sewage and Industrial Wastes Assn.	Wenonah Hotel Bay City, Mich.	May 11–13, 1959
Alabama Water and Sewage Assn.	University of Alabama University, Ala.	June 3–5, 1959
Maryland-Delaware Water and Sewage Assn.	Commander Hotel Ocean City, Md.	June 3–5, 1959
New York Sewage and Industrial Wastes Assn. (*Spring Meeting*)	Saranac Inn Upper Saranac Lake, N. Y.	June 8–9, 1959
Ohio Sewage and Industrial Wastes Treatment Conf.	Netherlands Plaza Cincinnati, Ohio	June 17–19, 1959
Iowa Sewage and Industrial Wastes Assn.	Roosevelt Hotel Cedar Rapids, Iowa	June 17–19, 1959

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Federation of Sewage and Industrial Wastes Associations
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Technical Meetings and Exhibits—Dallas Memorial Auditorium
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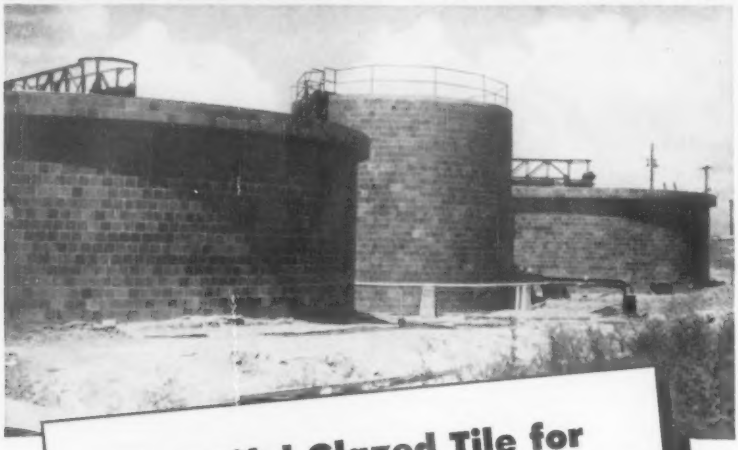

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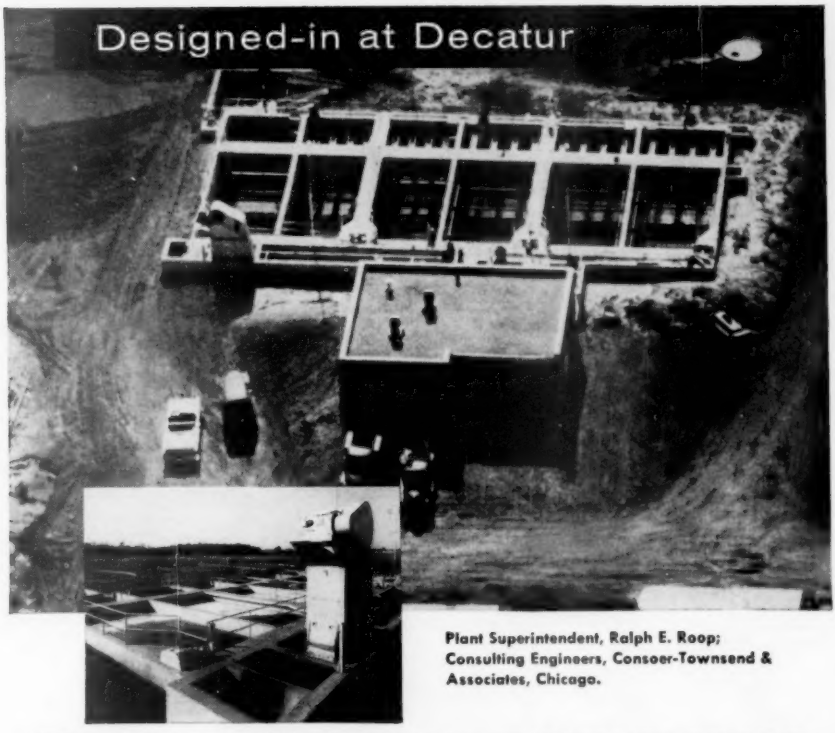

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To translate compactness into efficient performance, CHAIN Belt modern waste treatment equipment was selected for both primary and final treatment stages. A Rex Chain and Bucket Type Grit Collector, installed in a 2′6″ wide x 42′6″ long x 4′ deep channel, provides effective removal of inorganic solids. A channel for future expansion was also constructed (see inset).

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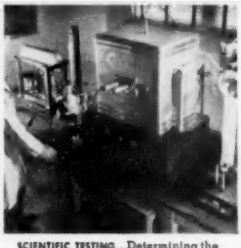
INSPECTING HOT PIPE... U. S. Pipe, just removed from the mold, is checked and inspected for quality.



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SPIRAGESTERS are used singly for projects under 6000 P.E. They give superior results with the minimum of operating skill. Construction and operating costs are among the lowest. Plant expansion available by adding another Spiragester or easily converting the tank to a digester. Spiragesters are now installed throughout the U. S. Also Canada and foreign countries. As at College Station, Lakeside provides trickling filter and Spiraflo final clarifier equipment for a complete treatment plant. *Write for Bulletin 100.*

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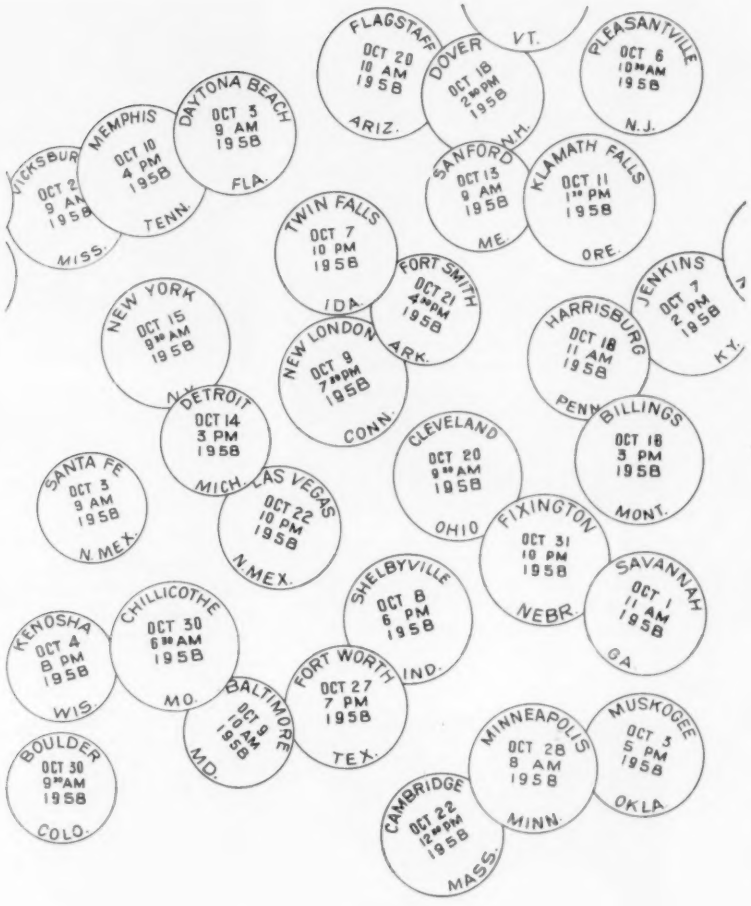
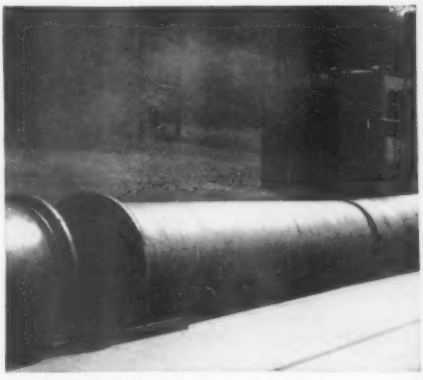


From North, South, East and West, officials wrote in to say...

"I PREFER CAST IRON PIPE TO ANY

Recently a questionnaire was mailed to water utility managers all over the U. S. One question asked was: *What kind of pipe do you prefer and why?* With 42 states heard from, the vote is overwhelmingly in favor of cast iron! Here are typical comments from the survey:



"Strength, resistance to corrosion . . . economical first cost, low maintenance and operating cost, good flow characteristics."

—North Carolina

"Our main system is entirely cast iron. It holds up good in 'hot' soil conditions and will not rust out. We are nearing the century mark on some of it, and it gives no trouble."

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OTHER KIND"

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- PRESSURE-TIGHT JOINTS. You have a complete choice of leak-proof, easy-to-assemble joints. You need a minimum of tools and crew.
- EASE OF TAPPING. No tapping saddles needed. Takes threading best of all kinds of pipe.

. . . *good reasons for* you *to choose*

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GASLIFTERS incorporate the patent rights of Joseph Cunetta

Above—Installation at Aurora Sanitary District, Aurora, Illinois serves to illustrate circulation and mixing action achieved with GASLIFTER. Published operating data attests to the resulting increased efficiency.

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Supt., Aurora Sanitary District
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Consulting Engineers

Engineers will be interested in Bulletin 25-S-91 for details on GASLIFTERS, and Brochure 25-S-11336 for complete report on GASLIFTER operating results at a full scale plant installation. Write for your copies.

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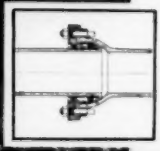

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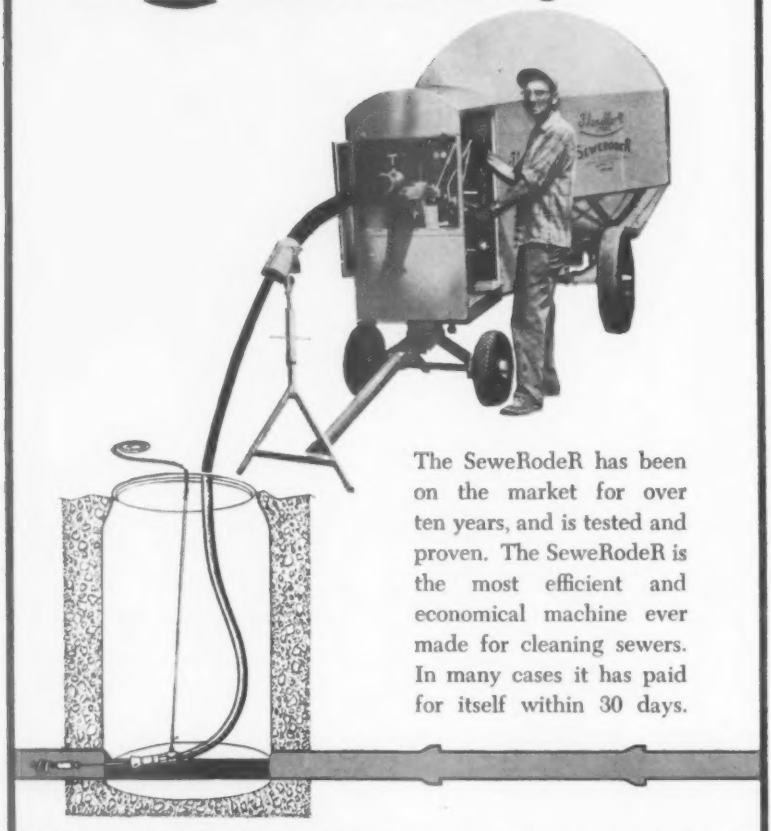

The SeweRodeR has been on the market for over ten years, and is tested and proven. The SeweRodeR is the most efficient and economical machine ever made for cleaning sewers. In many cases it has paid for itself within 30 days.

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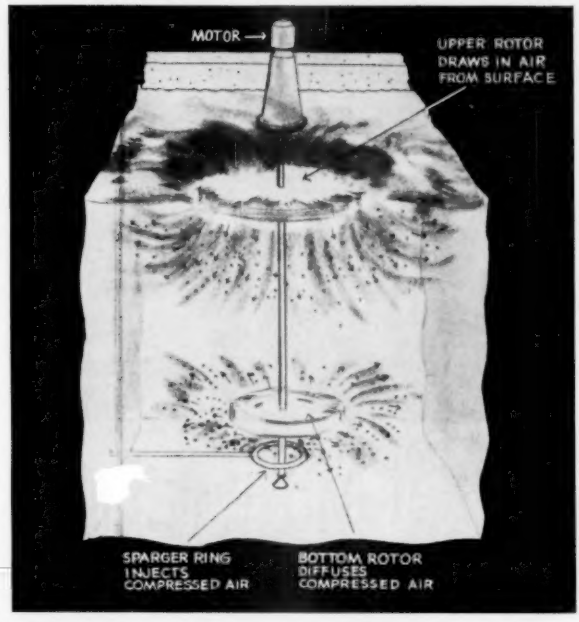

FLUIDICS AT WORK

New PERMUTIT AERATOR

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Specialists in FLUIDICS . . . the science of fluid treating and processing.

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120-Foot Outfall Installed in One Piece

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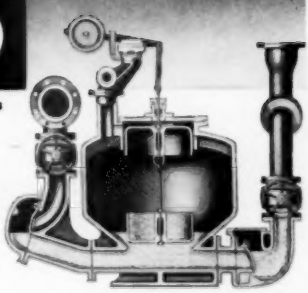

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IT'S NEW / It's from DORR-OLIVER

Close up view of new Degritting Chamber (left center) installed at a Dorr Clarigester at the Garden City, Idaho, Sewage Treatment Plant. Other D-O equipment at Garden City includes a 35 dia. S.P. Thickener, 10' dia. R.C.S. Thickener and a 1 1/4 pump.

A DEGRITTING CLARIFIER

A new two-in-one unit for small sewage treatment plants, the Dorr Degritting Clarifier or Clarigester combines positive mechanical degritting with conventional clarification in a single tank. Applicable for maximum flows of 0.45 to 1.75 MGD, this new design incorporates an annular chamber around the Clarifier feed well.

As Clarifier feed enters the chamber, grit settles and is removed by rakes attached to the Clarifier skimming arm. Overflow from the grit chamber discharges over a weir into the feed well. A by-pass slide gate allows discharge of the feed directly into the Clarifier when desired.

This new design is equally adaptable to both Dorr Type 'A' Clarifiers and Dorr Clarigesters. In either case, it will remove troublesome grit from the raw sewage without the need for costly, separate grit handling facilities.

For more complete information on this new two-in-one unit write Dorr-Oliver Incorporated, Barry Place, Stamford, Connecticut.

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Sewage Works

OVERFLOWS OF SANITARY SEWAGE FROM COMBINED SEWERAGE SYSTEMS *

By Thomas R. Camp

Camp, Dresser and McKee, Consulting Engineers, Boston, Mass.

The older portions of the sewerage systems in most of our cities and towns were constructed on the combined plan to receive both sanitary sewage and storm-water runoff. The disadvantages of this plan became evident during the past few decades as the municipalities have found it necessary to treat the sanitary sewage to abate pollution in the receiving streams. As a consequence, most new systems and extensions to old systems are now constructed on the separate plan with separate storm drains to receive the runoff from rainstorms. If the combined sewers have adequate capacity for both the sanitary sewage and storm-water runoff, it is not usually economically feasible to intercept and treat the entire flow from the combined sewers. It is thus necessary to accept overflows of mixed sanitary sewage and storm water into the receiving stream during rainstorms. With rainstorms of only moderate intensity a large part of the sanitary sewage is discharged untreated into the receiving stream. Such overflows constitute a major problem in the nation's pollution abatement program.

Design Practices

It has been shown independently by McKee (1), by Palmer (2), and by Johnson (3) that the average dry weather flow of sanitary sewage is approximately equal to the runoff from a rainstorm having an intensity of about 0.01 in./hr. It is common practice in the design of storm drains to provide capacities for rainstorms having frequencies ranging from 5 years for residential communities to 25 years for business districts in large cities. The corresponding rates of runoff range from about 0.5 to about 2 in./hr. It is thus evident that the capacity of properly designed combined sewers ranges from about 50 to about 200 times the average dry weather flow of sanitary sewage. It is for this reason that it is not usually economically feasible to intercept and treat the entire capacity of combined sewers. There are, however, in many municipalities some combined sewers which have grossly inadequate capacity for storm-water runoff. In such cases consideration should be given to intercepting the full capacity of the combined sewers.

It has long been general practice in the design of interceptors and treatment works to provide sufficient capacity for the estimated future peak dry weather flow of sanitary sewage together with a small amount of storm-water runoff commonly referred to as "first flushings." This practice results in providing interceptor capacities of from 2 to 5 times the average

* Presented at the 30th Annual Meeting, New England Sewage and Industrial Wastes Assn.; Hartford, Conn.; Nov. 5–6, 1958.

dry weather flow of sanitary sewage. This ratio is sometimes referred to as the "dilution factor."

Investigations and Results

Relationship of Rainfall Intensity to Dry Weather Flow

In connection with an engineering investigation in 1946 for sewage disposal in the Merrimack River Valley Sewerage District in Massachusetts, studies were made by McKee (1) of the U. S. Weather Bureau's hourly rainfall records in Boston during the months of June through November for the years 1934 to 1945 inclusive. McKee concluded that a rainfall of about 0.03 in. is required to produce runoff to the sewers and that a rainfall intensity of about 0.01 in./hr would produce runoff equal to the average dry weather flow of sanitary sewage. In Detroit, Palmer (2) collected data on the amount of rainfall necessary to cause runoff. Palmer's studies were by field observation and measurement using portable rain gages. The results of Palmer's observations indicated that, on the average, runoff did not occur unless the precipitation exceeded 0.03 in. per hour. Palmer, like McKee, found that the average sanitary flow is equivalent to a rainfall of about 0.01 in./hr. In studies of the sewerage system in Washington, D. C., Johnson (3) found that rainfall in excess of 0.02 in. is required to produce runoff into the sewers. He also found that the average dry weather flow of sanitary sewage was approximately equal to a rainfall intensity of 0.009 in./hr.

Loss of Sanitary Sewage

McKee (1) found from his study of the Boston rainfall records that rainfall equal to or in excess of 0.01 in./hr occurred 6.64 per cent of the total time and that rainfall sufficient to cause runoff into the combined sewers occurred about 5.62 per cent of the time. He also found that, with interceptors having a capacity of twice the average dry weather flow, 2.7 per cent of all the sanitary sewage produced during June through November may be expected to escape to the receiving stream during rainstorms. This means that approximately 97.3 per cent of all sanitary sewage will be intercepted and conveyed to treatment works. McKee's findings also indicated that, if interceptors are designed for 5 times the average dry weather flow, about 1.2 per cent of all the sanitary sewage will be lost to the receiving stream during overflows.

McKee's studies show that even though only a small per cent of the total flow of sanitary sewage in both dry and wet weather is lost in stormwater overflows, a very large per cent of the sanitary sewage present in the combined sewers during rainstorms is lost through overflows. For example, with interceptors having a capacity of twice the dry weather flow, more than 90 per cent of the sanitary sewage is discharged in the overflows with a rainfall intensity of 0.2 in./hr or more. With interceptors having a capacity of 5 times the dry weather flow, about 76 per cent of the sanitary sewage is lost during rainstorms having an intensity of 0.2 in./hr and about 90 per cent is lost during rainstorms having an intensity of 0.5 in./hr. These figures are based on the assumption that the combined sewers have sufficient capacity for a 5-year storm or a larger one. It is obvious from these figures that gross pollution of the receiving waters occurs for short durations during rainstorms. This is particularly objectionable in cases where the receiving waters are used for water supplies, swimming, or shellfish propagation and require low counts of coliform bacteria.

It has long been known that, with interceptors designed for two to three times the average dry weather flow,

only a very small portion of the total sanitary sewage will be lost in overflows and the duration of these overflows will be only a very small portion of the total time. For example, as pointed out by McKee (1), the Metropolitan Drainage Commission at Minneapolis and St. Paul, Minn., reported in 1928 that overflows would occur 1.7 per cent of the total time and that 1.1 per cent of the total sewage would be discharged untreated to the river. In a discussion of McKee's paper, Stanley (4) showed that a rainfall intensity equal to or greater than 0.04 in./hr occurs in Chicago about 1.6 per cent of the total time. Palmer (2) found in Detroit that rainfall intensities in excess of 0.04 in./hr occur about 2.5 per cent of the total time. Thus it appears that with interceptors designed for 2 to 3 times the average dry weather flow, it is generally true in the Northeast that only about 2 per cent of the total sanitary sewage overflows during rainstorms and that this occurs during only 2 to 6 per cent of the time. While the pollution caused by these overflows is insignificant in terms of the total annual volume of sewage and the total time, the effect of these overflows on the receiving waters will depend on the use and nature of the receiving waters and the frequency of the overflows.

Frequency of Overflows

Little importance appears to have been attached to the frequency of overflows prior to the studies by McKee (1) about twelve years ago. McKee's studies showed that with interceptors designed for 1.5 to 3 times the average dry weather flow, overflows may be expected from 5 to 6 times per month on the average during the summer months. This means every 5 or 6 days, much too frequent for waters to be used for bathing or shellfish propagation. McKee's studies also showed that even with interceptors having capacities for 20 times the average dry weather flow, overflows would occur about twice a month or every 15 days on the average. Thus, these overflows are not only very damaging to the recreational use of the receiving waters, but it is not economically feasible to obtain a satisfactory reduction in the frequency of overflows by increasing the interceptor capacity. These are very important findings.

In the studies made by Palmer (2) in Detroit, based on the records of the Conner Creek storm water pumping station, it was found that overflows would occur about 7 times per month on the average throughout the year with interceptors designed for twice the average dry weather flow. It was further found that with interceptors designed for 7 times the average dry weather flow, overflows would occur about 5.4 times per month on the average. These observations in Detroit are verification of the reasonableness of the findings by McKee based on the Boston rainfall records. Palmer concluded that no satisfactory reduction in the number of storm-overflow occurrences can be made by any reasonable increase in interceptor capacity.

The recent studies of the Washington sewerage system reported by Johnson included a 12-month period of gaging at a number of storm water overflow points. These gagings showed an overflow frequency of about 5 times per month for interceptors with a dilution factor of 1.5 to 2. The gagings also showed that from 1 to 3 overflows would occur per year with interceptors having a dilution factor of 66 to 100. These measurements are also in verification of the reasonableness of McKee's findings.

Effect of Concentration Time

In estimating storm-water runoff for the design of storm drains or combined sewers by the rational method,

rainfall intensity—duration curves are used. The rainfall intensity used for design is the average intensity throughout a duration period equal to the time of concentration of the runoff from the most remote part of the tributary area to the point in the system where the drain or combined sewer is to be sized. At the velocities of 2.5 ft/sec or more which will obtain in the drains or combined sewers during the design flows, the times of concentration which are of interest to the designer range from about 10 min to about 2 hr.

It should be noted that with low-intensity rainfalls, which are the cause of the frequent overflows, the velocities in the combined sewers are very much less than the velocities when the sewers are flowing at or near capacity. In estimating the frequency of overflows, therefore, concentration times of 2, 3, and 4 hr should be considered.

In McKee's study of the Boston rainfall record (1), the number of days per month in which various low intensity rainfalls were equaled or exceeded was noted. No storms were counted unless (a) the total rainfalls exceed 0.04 in., of which 0.03 in. was allowed for wetting and the first 0.01 in./hr thereafter was assumed to be intercepted and (b) the storm was followed by at least 24 hr during which no overflow occurred. In other words, two periods of overflow within 24 hr were considered as one storm and rated at the maximum intensity. Moreover, the intensity during only one hour was considered. This is equivalent to the assumption that all tributary areas have a concentration time of 60 min.

Comparison of Frequencies of Overflow

Boston, Mass.

The author's firm has recently restudied the rainfall records analyzed by McKee (1) to check the results he obtained on frequency of overflows and to extend the times of concentration to 2, 3, and 4 hr. The results of these studies are shown on Figure 1 by means of plotted points to which light solid curves have been fitted. The results obtained by McKee for a 60-min concentration time are plotted in a heavy broken line. The graph shows that the results of the recent computations for the 60-min period are in substantial agreement with McKee's original curve.

It will be noted from Figure 1 that with concentration times of 2, 3, and 4 hr, the frequency of overflows is progressively lowered. The effect is not great with interceptors having capacities of 1.5 to 2 times the average dry weather flow. With a 60-min concentration time, overflows may be expected about 6 times per month on the average whereas with 4 hr concentration time, overflows may be expected about 4.5 times per month on the average. The effect of concentration time on the frequency of overflows is much greater, however, with interceptors of large capacity. Figure 1 indicates that with interceptors having capacities of 20 times the average dry weather flow, overflows may be expected about 2 days per month on the average with a concentration time of 60 min, but only about 6 times per year if the concentration time is 4 hr.

Detroit, Mich.

Also shown on Figure 1 for purposes of comparison are the results of studies made by others on the frequency of overflows. The results of the studies made by Palmer (2) at Detroit are shown by a light dash-dot line. These studies cover a 12-month period, and, as previously noted, were for a 60-min concentration time.

Washington, D. C.

The results of measurements made in Washington under the direction of Johnson (3) are shown by large black

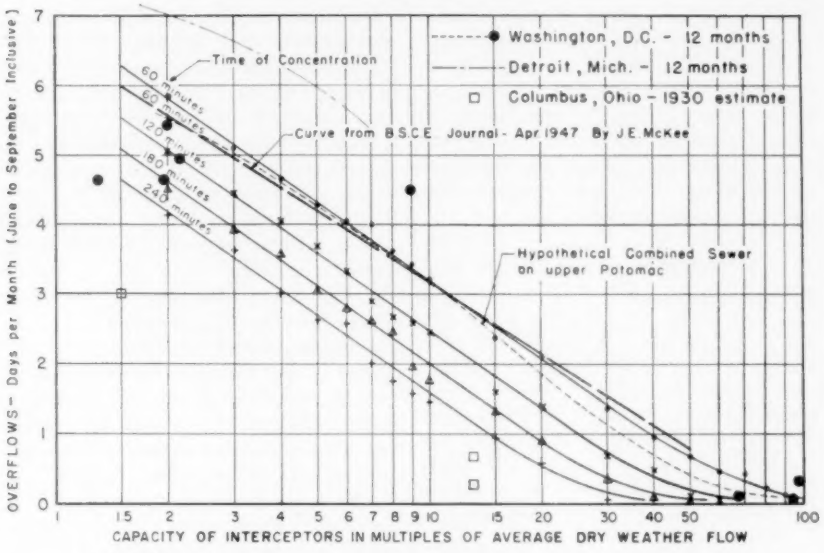

FIGURE 1.—Frequency of overflows based on Boston rainfall records.

dots. These measurements were taken over a 12-month period. The frequency of overflows observed in Washington is reliable; but Johnson indicates that the dilution factor for each of the points had to be estimated and there is some doubt as to its accuracy for some of the stations. Also shown on Figure 1 by means of a light dashed curve is the estimated frequency of overflows for a hypothetical combined sewer on the upper Potomac River at Washington. This curve was estimated from the measured points at other stations.

Columbus, Ohio

Figure 1 also shows, by means of open squares, overflow frequencies estimated by Gregory *et al.* (5) for Columbus, Ohio, about 1930. Rainfall intensities in Columbus were computed for different durations and frequencies from the records of the U. S. Weather Bureau for the years 1897 to 1923 inclusive. Intensity-duration curves for frequencies ranging from 8 times per year to once in 15 years were plotted with durations ranging from 5 min to 2 hr. The estimated frequency of overflows shown on Figure 1 for Columbus were determined from the intensity-duration curves. It will be noted that the estimated frequency of overflows for Columbus was considerably less than might be expected from the more recent studies elsewhere.

Concord, N. H.

Recently, studies were completed of the hourly rainfall records at Concord, N. H., for the months of June to September inclusive and for the years 1953 to 1957 inclusive. The estimated frequency of overflows from combined sewers in Concord is shown by the curves in Figure 2. Figure 2 indicates that with interceptors designed for the peak dry weather flow, overflows may be expected into the Merrimack River at Concord from four to six times per month on the average during the summer months. This is a slightly higher frequency than was indicated by the Boston rainfall rec-

ords. The Concord data indicate about the same frequency of overflows as the Boston rainfall data for interceptors of large capacity. With a dilution factor of 20, overflows may be expected about once every 2 months with a 4-hr time of concentration to about twice per month with a 1-hr time of concentration.

Significance of Overflows

Pollutional Aspects

The overflows of mixed sewage and storm water constitute slugs of pollution in the receiving waters of high concentration at the points of discharge. When the receiving waters are lakes or tidal estuaries, the slugs of pollution hover about the overflow points in relatively strong concentrations to be dispersed gradually by tidal currents or wind-induced currents. Both tidal currents and wind-induced currents may carry slugs of pollution for thousands of feet before satisfactory dilution occurs by mixing with the receiving waters. When the receiving waters are flowing streams, the slugs of pollution will be carried downstream and the rate of dilution by mixing with the receiving waters will depend upon the velocity and turbulence of the stream. In large, slow-velocity rivers slugs of pollution are known to hug the shore on the side where the discharge occurs.

If a receiving water is classified for a use which requires a considerably smaller concentration of pollution than occurs in the slugs of pollution discharged in storm water overflows, either the pollution from the storm water overflows must be eliminated or the frequency of the overflows must be substantially reduced and the receiving waters must be capable of purging themselves of pollution rapidly following rainstorms. Moreover, if the receiving waters are to be used as municipal supplies following treatment, they must be capable of providing adequate dilution of the pollution between the points of overflow and the water works intake. In the author's opinion the only completely satisfactory solution is the elimination of the

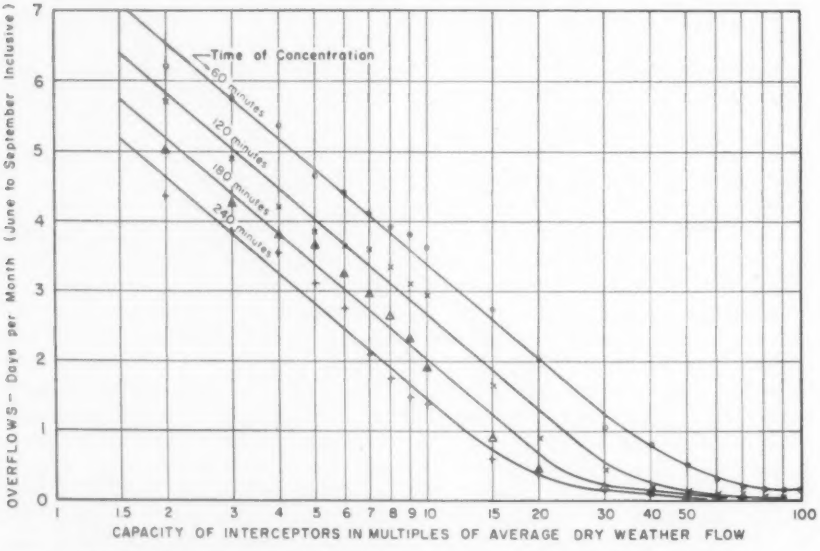

FIGURE 2.—Frequency of overflows based on Concord rainfall records.

overflows of mixed sewage and storm water; but this may prove to be so costly as to warrant a downgrading of the use classification or the related water quality standard together with steps leading to partial accomplishment of the ultimate goal such as separation of parts of the system and large interceptors for other parts.

Cost of Remedial Measures

Palmer, in his 1949 Detroit studies (2), estimated that complete separation of the Detroit system would cost approximately $235,000,000 which is roughly $130 per capita. Johnson reported in 1958 that the District of Columbia's Board of Engineers estimated that it would cost about $238,000,000 to convert the large combined sewer area of Metropolitan Washington to separate systems, not including indirect losses to property owners, business men, and others. Complete separation at Concord, New Hampshire is estimated at approximately $8,000,000 or $280 per capita. These are extremely high costs to add to the initial cost of interception and treatment of the dry weather flow, and they must be weighed against the value of the use of the receiving water course which will be made possible by the separation program. If, for example, the desired use is swimming, this demand can be met by the construction of swimming pools at a fraction of the cost of separation. If the desired use is for municipal water supplies, this demand can be met by more adequate treatment at water filtration plants at generally far less cost than the cost of separation of the sewers.

Conclusions

The problem of what to do about pollution associated with overflows of mixed sanitary sewage and storm water from combined systems is an extremely complex one involving in most cases enormous cost for each alternate solution. The solution must be tailor-made for each municipality. To meet this problem economically for all concerned, realistic appraisals must be made of the values of the proposed uses of the receiving waters as compared with the cost of meeting the water quality standards associated with these uses. These appraisals must be made by the pollution control agencies before the streams are classified.

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PLAN FOR DALLAS

32nd Annual Meeting of Federation of Sewage and Industrial Wastes Associations with host, Sewage and Industrial Waste Section of Texas Water and Sewage Works Association, October 12–15, 1959, at the Statler Hilton Hotel, Dallas, Texas. Technical meetings and exhibits: the Dallas Memorial Auditorium.

EFFECTS OF PREMIXING RAW AND DIGESTED SLUDGE ON HIGH-RATE DIGESTION

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Investigations were begun in 1954 and continued until the early part of 1958 at the sewage-treatment works serving the city of Baltimore, Md., to determine the extent to which the rate of digestion of raw sludge could be increased by increasing the quantity of seeding material. These experiments were conducted first in the laboratory and later on a plant scale and indicated that satisfactory digestion could be obtained in 10 days or less when one part of digested sludge is premixed with one part of raw sludge (organic matter weight basis) and when the mixture is subjected to anaerobic decomposition at the proper temperature.

In 1927 Rudolfs (1) reported that raw sludge to which no ripe sludge was added digested in 54 days when kept at 29.5°C. Fair and Carlson (2), Rudolfs and Heukelekian (3), and Keefer and Kratz (4) are among those who reported that fresh sludge could be digested in 25 days to 6 weeks, depending on the sludge temperature maintained. In all of these experiments one-half part of digested sludge was mixed with one part of raw sludge by weight on the volatile solids basis. Since the introduction of one-half part of digested sludge to one part of raw sludge on the volatile solids basis will reduce the digestion time from 54 to about 30 days, the question naturally arises as to whether the digestion time can be further reduced by using larger quantities of digested sludge. To answer this question a series of experiments were conducted in the laboratory at the Patapsco sewage treatment works and on a full scale in the field at the Back River sewage treatment works, both of which plants serve the city of Baltimore.

Laboratory Experiments

The sewage received at the Patapsco plant was domestic in character and of average strength. Sludge for the tests was drawn from this waste. At the time the experiments were conducted, the plant was provided with two mechanically-cleaned settling tanks with a theoretical detention period of about 2 hr, and one square digester with a capacity of 78,000 cu ft.

Several groups of tests were made using mixtures of various ratios of raw and digested solids. The results of three of these tests will be discussed herein. These ratios were based on the weights of raw volatile solids in the two materials. During all of the tests the sludges were kept in an incubator room at a temperature of 37°C.

Experiment No. 1

During experiment No. 1, five different mixtures of digested and raw sludge were prepared and put into five 5-gal carboys. The ratios of digested solids to raw solids were 0.5, 1, 2, 4, and 5. The digested sludge used for seeding purposes was drawn from the digester at the Patapsco sewage works and was stored in the laboratory until gasification ceased. The material was then thoroughly mixed, divided into five parts, and samples in duplicate were obtained from each part for analysis. A sufficient quantity of raw sludge was also collected and analyzed. The raw and the digested sludges were mixed in

TABLE I.—Analyses of Raw and Digested Sludges Used During Experiment No. 1

Ratio of Digested to Raw Sludge*	Digested Sludge				Raw Sludge			
	Quantity Used (ml)	Total Solids (per cent)	Volatile Content		Quantity Used (ml)	Total Solids (per cent)	Volatile Content	
			Dry Basis (per cent)	Dry Weight (g)			Dry Basis (per cent)	Dry Weight (g)
0.50:1	2,000	6.60	44.66	58.95	3,015	5.25	74.46	117.90
1:1	2,500	6.77	44.23	74.86	1,910	5.26	74.54	74.86
2:1	4,000	6.87	44.73	122.92	1,605	5.19	73.76	61.46
4:1	4,000	6.79	44.60	121.13	780	5.24	73.99	30.28
5:1	4,000	6.62	44.86	118.79	616	5.19	74.25	23.76

* Ratio is based on weights of dry volatile solids.

accordance with the above-mentioned ratios and added to the five carboys. The quantities and the analyses of sludges are given in Table I.

The top of each carboy was connected by tubing to a sealed 5-gal carboy containing a displacement solution to collect and measure gases containing CO_2 (5). By measuring the quantity of the displaced solution, the quantity of gas generated by the sludge in each bottle could be determined. The volumes of gas produced were, in general, measured daily. All gas volumes were corrected to a temperature of 0°C and a pressure of 760 mm of mercury. For the most part, the gas was analyzed daily for CH_4 and CO_2. The pH of the sludges were determined at frequent intervals; if the pH dropped below 6.8, $Ca(OH)_2$ was added. Twice a week the moisture and the volatile

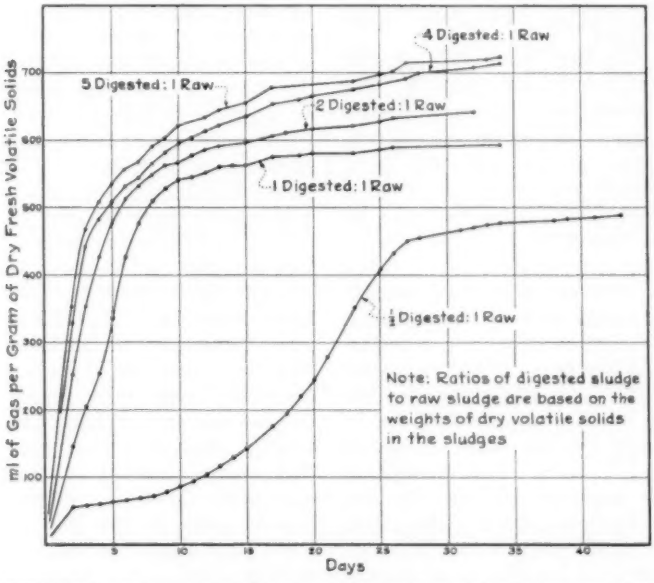
4 Digested: 1 Raw
5 Digested: 1 Raw
2 Digested: 1 Raw
1 Digested: 1 Raw
½ Digested: 1 Raw
Note: Ratios of digested sludge to raw sludge are based on the weights of dry volatile solids in the sludges
ml of Gas per Gram of Dry Fresh Volatile Solids
Days

FIGURE 1.—Gas produced by raw sludge seeded with varying quantities of digested sludge in Experiment No. 1.

TABLE II.—Digestion Time, Sludge Analyses, and Gas Production, Experiment No. 1

Ratio of Digested to Raw Sludge*	Digestion Time (days)	Analysis at End of Digestion Period		Gas Production				
		Total Solids (per cent)	Volatile Solids, Dry Basis (per cent)	Per Gram of Dry Fresh Volatile Solids			Gas Produced in Excess of Control (per cent)	
				Total Gas (ml)	CH_4		Total Gas	CH_4
					(ml)	(per cent)		
0.5:1†	26¼	4.96	45.23	490	320	65	—	—
1:1	8½	4.88	45.02	595	375	63	21	17
2:1	11	5.67	43.52	640	425	66	31	33
4:1	15½	6.16	43.04	715	490	68	46	53
5:1	14½	6.05	42.19	725	490	68	48	54

* Ratio is based on weights of dry volatile solids.
† Control.

content of duplicate samples of the sludges were determined.

Figure 1 gives the quantities of gas produced by each of the five sludge mixtures. The sludges were kept in the incubator until all gas production had ceased. In determining the time required to digest the sludge during this experiment and the next two, digestion has been considered to be completed when 90 per cent of the gas evolved had been produced.

When one-half part of digested sludge (Figure 1 and Table II) was added to one part of ripe sludge, which mixture served as the control, the digestion period was 26¼ days. This digestion period was anticipated and agrees with observations by numerous investigators using similar proportions of seeding material. When the ratio of digested to raw volatile solids increased to 1:1, the digestion period lowered to 8½ days, a reduction of 67.5 per cent. When the ratios of digested to raw solids were further increased, there was some increase in the digestion periods when compared with the 1:1 ratio. For example, a 2:1 ratio required 11 days for the sludge to digest, a 4:1 ratio, 15½ days, and a 5:1 ratio 14½ days. It is interesting to note, however, from Figure 1 that as larger quantities of seeding material were used the rate of digestion increased; that is, more of the organic material was being converted into gas per unit of time. Of unusual interest was the observation that the total quantity of gas produced per gram of dry fresh volatile solids increased rather uniformly as larger amounts of seeding materials were used. For example, the control produced 490 ml of gas per gram of dry, fresh volatile solids, and the sludge mixture containing a ratio of 5 parts of digested solids to 1 part of raw solids produced 725 ml of gas per gram of dry fresh volatile solids, an increase of 48.0 per cent. No entirely satisfactory explanation of this phenomenon is apparent. This observation was in evidence not only during Experiment No. 1 but also consistently during subsequent experiments. It is possible that when raw solids are brought into intimate contact with large quantities of digested sludge, the superabundance of bacteria present may decompose the organic matter to a greater extent than would normally be the case with smaller quantities of seeding material. That this explanation seems plausible is apparent by examining Table II, which gives the volatile solids in the five sludge mixtures when digestion had ceased. The volatile solids (dry basis) decreased rather uniformly from 45.23 per cent in the control to 42.19 per cent in the

mixture containing a 5:1 ratio of digested to raw volatile solids. This latter 42.19 per cent was less than the proportion of volatile solids in the seeding material at the beginning of the experiment, which was 44.86 per cent. As the foregoing ratios were increased there was a further decomposition of the volatile solids either in the seeding or in the raw solids.

Although gas production continued in the three bottles containing ratios of digested to raw solids of 2:1, 4:1, and 5:1 beyond the 8½-day digestion period, considered complete in the bottle containing a 1:1 ratio, for all practical purposes the sludges in these three bottles were digested at the end of 8½ days, as evidenced by their physical and chemical characteristics.

Another observation of interest related the extent to which the per cent of CH_4 in the sludge gas varied with the ratio of digested to raw sludge in the mixtures. Table II indicates that when larger quantities of seeding materials were used there was some increase in the proportion of CH_4 in the gas.

Experiment No. 2

Experiment No. 2, conducted from July 21 to August 20, 1954, included studies of the mixing of raw and digested sludges, using five different ratios of digested volatile solids to raw volatile solids. These ratios were 1:1, 2:1, 4.0:1, 6.0:1, and 7.74:1. The method of conducting the experiment, including the collection and analysis of the samples, was the same as that for Experiment No. 1. The quantities and the analyses of the raw and the digested sludges at the beginning of the experiment are given in Table III. Figure 2 shows the gas production for each of the five mixtures. Table IV shows the digestion to be completed in 8½, 9¼, 10¾, 12¼, and 14¾ days for the respective mixtures. The greater the quantity of ripe sludge used, the greater was the rate of gas production, and the greater was the total quantity of gas produced. For example, 650 ml of gas was produced per gram of dry fresh volatile solids with a 1:1 ratio and 950 ml with a 7.74:1 ratio, an increase of 46.0 per cent. As in Experiment No. 1, when a greater ratio of digested to raw sludge was used, there resulted a gas production with a higher CH_4 content. The gas contained 69.4 per cent of CH_4 from a 1:1 ratio and 72.7 per cent from a 7.74:1 ratio. As greater ratios were used, the percentage of volatile solids in the digested material was less, which condition indicated a greater degree of digestion.

Experiment No. 3

After finishing the first two experiments, it was considered essential to check the results of these experiments

TABLE III.—Analyses of Raw and Digested Sludges Used During Experiment No. 2

Ratio of Digested to Raw Solids*	Digested Sludge				Raw Sludge			
	Quantity Used (ml)	Total Solids (per cent)	Volatile Content		Quantity Used (ml)	Total Solids (per cent)	Volatile Content	
			Dry Basis (per cent)	Dry Weight (g)			Dry Basis (per cent)	Dry Weight (g)
1:1	2,500	7.45	45.02	83.85	2,572	4.57	71.24	83.85
2:1	4,000	7.77	44.14	137.19	2,104	4.49	72.62	68.60
4.01:1	4,000	7.73	44.42	137.35	1,075	4.34	73.53	34.28
6.00:1	4,000	7.65	44.69	136.75	710	4.39	73.16	22.79
7.74:1	4,000	7.74	44.99	139.30	544	4.43	72.18	17.99

* Ratio is based on weights of dry volatile solids.

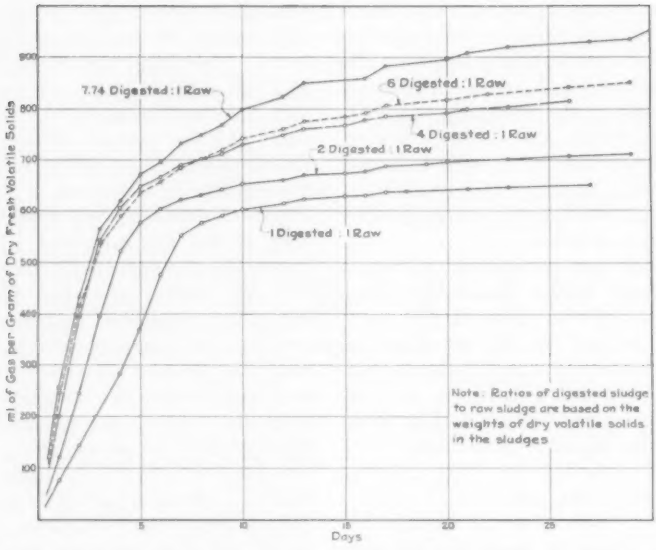
7.74 Digested : 1 Raw
6 Digested : 1 Raw
4 Digested : 1 Raw
2 Digested : 1 Raw
1 Digested : 1 Raw
Note: Ratios of digested sludge to raw sludge are based on the weights of dry volatile solids in the sludges
ml of Gas per Gram of Dry Fresh Volatile Solids
Days

FIGURE 2.—Gas produced by raw sludge seeded with varying quantities of digested sludge in Experiment No. 2.

by digesting a larger quantity of raw sludge. To do this a 55-gal steel drum was fitted with an air-tight cover and used as the digester. A total of 52,850 ml of raw sludge was put into the drum to which was added 75,000 ml of digested sludge. The two materials were thoroughly mixed, the drum was sealed, and provisions were made for determining the volume of gas produced by measuring the quantity of solution displaced from another steel drum by the gas. Figure 3 shows the equipment.

Table V gives the analyses of the two sludges. The ratio of digested volatile solids to raw volatile solids was 1.5 : 1. The pattern of gas measurement and analysis as well as contents analysis was the same as that followed in the earlier experiments. The total gas and methane produced during the experiment are shown in Figure 4. If

TABLE IV.—Digestion Time, Sludge Analyses, and Gas Production, Experiment No. 2

Ratio of Digested to Raw Sludge*	Digestion Time (days)	Analysis at End of Digestion Period		Gas Production				
				Per Gram of Dry Fresh Volatile Solids			Gas Produced in Excess of 1:1 Ratio (per cent)	
		Total Solids (per cent)	Volatile Solids, Dry Basis (per cent)	Total Gas (ml)	CH_4		Total Gas	CH_4
					(ml)	(per cent)		
1:1	8½	5.02	45.50	650	450	69	—	—
2:1	9½	5.86	44.22	710	505	71	9	12
4.01:1	10¾	6.40	44.26	820	590	72	26	31
6.0:1	12¼	6.90	42.96	850	620	73	31	37
7.74:1	14¾	7.11	43.18	950	690	73	46	53

* Ratio is based on weights of dry volatile solids.

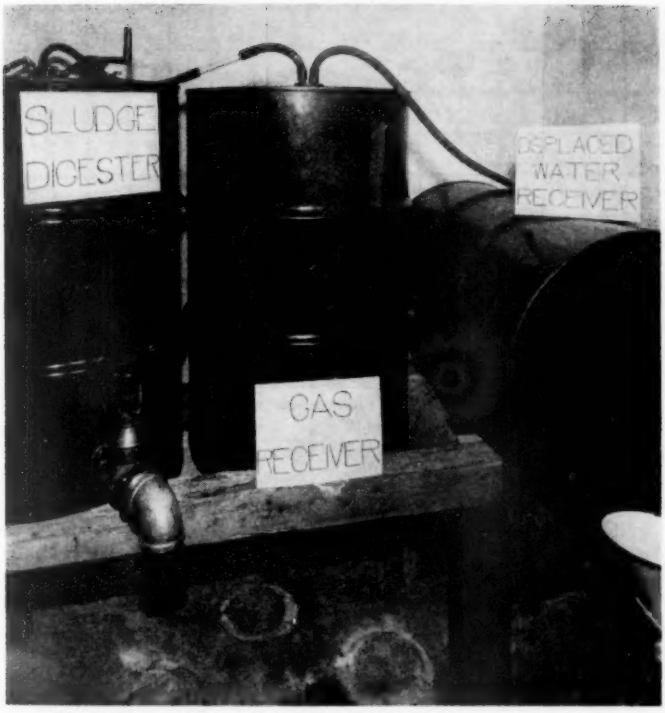

FIGURE 3.—Digestion equipment used in Experiment No. 3.

it is assumed that decomposition was complete when 90 per cent of the gas had been produced, 12½ days were required to digest the material.

The results when the sludge was digested in the 55-gal drum were comparable with those obtained when 5-gal carboys were used. The time required to digest the sludge, the quantity and the analysis of the gas produced, and the physical and chemical characteristics of the digested materials were approximately the same.

Field Experiments

The full-scale field experiments for determining the speed of digestion when known quantities of raw and digested sludges were premixed and then subjected to digestion were conducted at the Back River sewage treatment plant, where approximately 95 per cent of the sewage from the city of Baltimore and the adjacent territory is treated. The sewage, which had an average 5-day BOD of 200 mg/l in

TABLE V.—Analysis of Sludges Used During Experiment No. 3

Item	Quantity (ml)	Dry Solids (per cent)	Volatile Solids, Dry Basis (per cent)	Ratio by Weight Dry Digested VS to Dry Raw VS
Raw sludge	52,880	5.34	63.94	—
Digested sludge	75,000	11.18	31.39	1.5
Mixture at end of digestion period	—	7.50	32.17	—

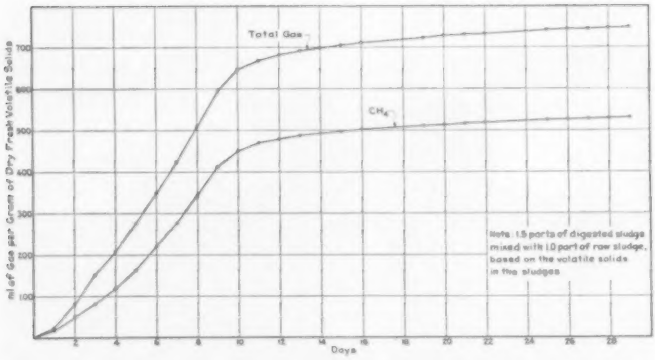
Total Gas
CH_4
ml of Gas per Gram of Dry Fresh Volatile Solids
Days
Note. 1.5 parts of digested sludge mixed with 1.0 part of raw sludge, based on the volatile solids in the sludges

FIGURE 4.—Gas produced by 52.89 liters of raw sludge seeded with 75 liters of digested sludge—Experiment No. 3.

1957, is derived from a separate system of sewers. The primary treatment units consist of mechanically-cleaned screens, grit chambers, and primary settling tanks. Secondary treatment units consist of trickling filters, mechanically-cleaned settling tanks, and activated sludge units, which are designed to treat an average flow of 20 mgd. The secondary settling tank sludge and the waste activated sludge are pumped back into the raw sewage. It is estimated that the raw sludge is composed of approximately 84 per cent primary solids, 11 per cent secondary settling tank solids from trickling filtration, and 5 per cent waste activated sludge solids.

Two identical sludge digesters were used in conducting the experiments, one of which served as a control. Each digester was 100 ft in diameter, 25 ft deep at the side walls, and was provided with a fixed concrete roof. The total capacity of each digester was 200,600 cu ft and the working capacity was 180,000 cu ft. The digester contents were not stirred during this test. The digesters were heated with hot water through 6-in. pipe coils. The quantity of sludge pumped into each digester was measured by Venturi meters, which were provided with indicating-recording-registering equipment. The volume of gas produced was metered. These volumes were not corrected for temperature and pressure. The temperature of the sludge in the digesters was determined by recording thermometers. Samples of the sludge added to or removed from the digesters were collected at frequent intervals and composited for total and volatile solids determinations.

The experiment was conducted during six irregularly spaced operating periods covering a total elapsed time of 14 months. During each period the liquid load introduced into the control digester was maintained at 90,000 gpd. The procedure in operating this tank consisted of draining off 90,000 gpd of digested sludge either through the 10-in. draw-off pipe at the bottom of the tank or through one of the sluice gates at the side of the tank. An equal quantity of raw sludge was then pumped into the digester over a period of about 1½ hr through pipes in the roof. Since the percentage of volatile solids in the raw sludge varied daily, the organic load introduced into the digester was not constant. The average load during the six operating periods varied (Table VI) from an average minimum of 22,900 lb of volatile solids per day or 0.127 lb/day/cu ft of digester space to an average maximum of 26,200 lb/day or 0.145 lb/day/cu ft of digester space. The temperature

TABLE VI.—Operating Data from Full-Scale Tests

Item	Period No. 1 (May 1–June 21, 1956)		Period No. 2 (July 1–Aug. 8, 1956)		Period No. 3 (Sept. 1–Sept. 23, 1956)		Period No. 4 (Nov. 1–26, 1956)		Period No. 5 (Dec. 1, 1956–Jan. 11, 1957)		Period No. 6 (May 13–July 31, 1957)	
	Control	Test Digester	Control	Test Digester	Control	Test Digester	Control	Test Digester	Control	Test Digester	Control	Test Digester
Raw sludge:												
Volume (gpd)	90,000	90,000	90,000	112,500	90,000	120,000	90,000	135,000	90,000	144,000	90,000	153,000
Dry solids (%)	4.9	4.9	5.0	4.8	4.5	4.3	4.8	4.8	4.4	4.4	4.9	4.8
VS (lb/day)	26,200	25,700	26,100	30,400	23,500	29,300	24,400	36,800	22,900	36,200[a]	25,880	42,610
VS (%, dry basis)	72.3	71.3	69.7	68.3	69.2	68.3	68.3	67.7	69.4	68.6	69.7	69.4
Digested sludge:												
VS (lb/day)	14,860	16,400	14,600	15,900	13,600	14,700	12,300	20,400	13,200	21,500	12,200	20,773
VS (%, dry basis)	59.3	57.6	55.2	54.4	56.3	53.6	57.6	56.2	58.8	58.2	57.7	58.2
Gas produced:												
cfd	196,000	189,000	195,000	201,000	191,700	243,600	139,500	194,000	123,000	188,000	181,240	244,270
cu ft/lb VS added	7.47	7.33	7.46	6.91	8.14	8.30	5.74	5.29	5.37	5.18	7.08	5.78
Sludge temperature (°F)	80.0	87.0	92.5	92.5	93.5	93.0	81.5	82.0	79.5	80.0	88.7	88.3

in the digester ranged from a minimum of 79.5 to a maximum of 93.5°F. The volatile solids in the digested sludge withdrawn from the tank ranged from 55.2 to 59.3 per cent, on the dry solids basis.

The test digester was identical in design with the control unit. A steel tank with a diameter of 9 ft 6 in. and a working depth of 4 ft 3 in. was erected adjacent to and used in conjunction with the operation of the test digester. Raw and digested sludges were pumped into this tank, thoroughly mixed by a motor-operated mixer operating at 420 rpm for several minutes, and delivered by gravity into the digester through pipes in the roof.

The operation of the test digester was similar to that of the control. A predetermined amount of digested sludge was removed each day from the digester. Then, as raw sludge was pumped into the mixing tank, digested sludge was drawn at the same rate from the digester and pumped back into the mixing tank, where the two sludges were mixed before they discharged into the top of the digester.

During the first 52 days 90,000 gal of raw sludge, which were premixed with 90,000 gal of digested sludge, were introduced each day into the test digester. During this period there was not a great deal of difference in the performance of the test digester and the control, which received the same amount of raw sludge and to which no digested sludge was added. There was a slight difference in the volatile solids in the digested sludges withdrawn from the two tanks. The sludge drawn from the control contained 59.3 per cent volatile solids and the sludge drawn from the test digester contained 57.6 per cent, on a dry weight basis.

During the second digestion period of 39 days, the liquid load added to the test digester was increased from 90,000 to 112,500 gpd, an increase of 25 per cent, and the volatile solids load was raised from 25,700 to 30,400 lb/

day, an increase of 18.3 per cent. In spite of this greater load the volatile solids in the digested sludge drawn from the digester were 54.4 per cent on the dry weight basis as compared with 55.2 per cent in the sludge produced by the control. At regular intervals thereafter the liquid load added to the test digester was increased to 120,000, 135,000, 144,000, and finally during the last period to 153,000 gpd, during which time the organic load averaged 42,610 lb/day or 0.236 lb/day/cu ft of digester space. The volatile solids in the digested sludge drawn from the two digesters during this period were comparable, amounting to 57.7 and 58.2 per cent, respectively. That decomposition was much more active in the test digester than in the control is indicated by the quantities of gas produced by the two tanks. The control digester produced 181,240 cu ft/day of gas and the test digester, 244,270 cu ft/day, an increase of about 35 per cent. With a loading of 153,000 gpd the theoretical time that the sludge remained in the tank was 8.8 days. As the digester had not been cleaned since December 1947, there was undoubtedly some accumulation of inert material in the tank, and consequently the digestion period was most likely somewhat less than 8.8 days.

Later experiments in which the sludge loadings to the digester were increased to 162,000 gpd indicated that the digester was at approximately its maximum operational limit at a loading of 153,000 gpd.

Discussion

The foregoing laboratory and plant-scale experiments have demonstrated the importance of the quantity of seeding material when premixed with raw sludge on the stimulation of high-rate sludge digestion. The laboratory experiments indicated that when one-half part by weight of digested volatile solids was mixed with one part of raw volatile solids and maintained at 37°F, about 26 days were required for the mixture to digest. This digestion time is comparable with that observed by other investigators when a similar ratio of the two materials is used. However, when the quantity of seeding material was increased by 100 per cent so that the digested solids to raw solids ratio was 1 to 1, the period required to digest the sludges was reduced to 8½ days.

The field experiments conducted at the Back River treatment plant using a digester with a working capacity of 180,000 cu ft indicated that satisfactory digestion could be obtained in about 9 days when equal volumes of raw and digested sludges were thoroughly premixed before they were introduced into the digester.

These experiments point to the fact that by thoroughly premixing raw and digested sludges in properly controlled amounts before introduction into a digester, a more rapid rate of digestion can be accomplished. The obvious advantages of increased capacity and design economy are evident.

The equipment required to accomplish these results is minimum. Two meters are required to measure the raw and the digested sludge, a tank with a detention period of about 5 min, and a mixer are needed. Automatic regulation equipment can be used to control the ratio of the quantities of sludge flowing through the two meters.

These experiments have reemphasized the importance of inoculating raw sludge to speed digestion. In 1914 O'Shaughnessy (6) indicated that digested sludge was pumped into a pipe line at Birmingham, England, through which raw sludge flowed, for the purpose of inoculating the latter material. In this same year Imhoff and Blunk (7) were granted a German patent, which involved the mixing of raw and digested sludges to promote the decomposition of raw sludge. Later Blunk and Prüss (8) were granted a German

patent, which covered circulating sewage sludge from the bottom to the top of a digestion tank. The equipment used for this purpose consisted of a vertical pipe suspended in the center of a digester. The bottom, or suction end of the pipe, which was open, terminated just above the tank floor. In the top of the pipe at the surface of the sludge was a motor-operated impeller. By operating the impeller, sludge could be drawn from the bottom of the tank and discharged radially outward over the surface of the sludge. By this means the tank contents could be circulated and at the same time some mixing of the raw and the digested materials would result. This pump was installed in a digester and tested (9) in 1932 and 1933 at the Back River sewage treatment works and it was concluded that sludge digestion was not accelerated. Since the Blunk-Prüss patent was granted and exploited, numerous other methods have been used to stir the contents of digesters. The extent to which the use of all the foregoing ideas has hastened digestion is open to question. As late as 1956, Imhoff (10) stated that the digestion of sludge takes 30 days at 27°C and a somewhat shorter time at 37°C. As described herein, two considerations seem important: (a) the importance of the quantity of seed material used to inoculate raw sludge is emphasized, and (b) the importance of sludge mixing is in evidence.

It is not enough to bring raw and digested sludges in contact with each other if high-rate digestion is expected. It is important to know the quantities of these materials to be mixed. It is also desirable to know the amount of volatile solids in each of the sludges. Using these data as a guide, the operator can then predict how long digestion will take at any temperature.

With regard to the inoculation of raw sludge with digested solids, it is essential that the bacteria in the ripe sludge be diffused and brought into intimate contact with the entire volume of raw sludge. It is questionable whether this can be done effectively by pumping the two materials through the same pipe line or by circulating the contents of a digester by means of a Blunk-Prüss pump or similar device. Raw sludge contains many materials that resist normal mechanical disintegration processes. The mixing equipment, therefore, must be such that the solids in the raw sludge are at least partially disintegrated and impregnated with seeding material. If this mixing is performed outside the digester, samples of the mixture can be obtained before it enters the digester and it can be determined whether the sludge is thoroughly mixed. Mixing the sludges outside the digester has another advantage; the mixture can be introduced at one or more places near the top of the digester. The direction of flow of the mixture will, in general, be downward inside the digester, and at the end of the digestion period the ripe sludge with the greatest age, solids content, and stability can be withdrawn from the bottom of the digester. If, however, the sludge in the digester is circulated or overturned by a mixing device in the tank, the withdrawn material will include undigested and partially digested solids.

Conclusions

The following conclusions have been drawn from the digestion experiments:

1. The proportionate quantity of digested sludge used to seed raw sludge has an important bearing on the rate of digestion of the raw solids.

2. Intimate mixing of digested and raw sludge is important to the digestion rate.

3. Raw solids can be digested in about 10 days if the weight ratio of digested volatile solids to raw volatile solids in a digester mixture is maintained at 1 to 1.

4. It was observed that more gas was produced per unit weight of raw volatile solids as the ratio of digested solids to raw solids was increased.

When using the principles of premixing of digested with raw sludge and in order to attain a predetermined digestion time it is important to maintain quantity control of the mixture of digested and raw sludges. Determining the necessary facts and evaluating them for this control is as important in the operation of sludge digesters as determining and controlling the temperature of the sludge undergoing digestion.

Application has been made for a United States patent involving the ideas contained in this discussion.

Acknowledgments

The Bureau of Sewers is under the direction of George A. Carter, Director of Public Works, and John J. Hunt, Sewerage Engineer. Dr. Abel Wolman is consultant to the Department of Public Works.

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SHORT COURSE

The Civil Engineering Department of Manhattan College is again offering a one-week course to present the fundamentals of bio-oxidation to provide the basis for use in the analysis, design, and operation of biological waste treatment facilities. This is titled "The Fourth Course on Bio-Oxidation of Organic Wastes, Theory and Design." Emphasis will be placed on applications of these principles to domestic sewage and several industrial wastes. The five-day course will be June 15–19 at Manhattan College. The fee is $100. Address all correspondence to: W. Wesley Eckenfelder, Jr., Civil Engineering Department, Manhattan College, New York 71, N. Y.

ECONOMICAL PRACTICES IN THE ACTIVATED SLUDGE AND SLUDGE DIGESTION PROCESSES *

By Richard H. Gould

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This is one of four papers collectively forming a sewage treatment cost reduction symposium. Others deal with construction, operation, and over-all regulatory considerations. The paper on construction cost reduction appears on page 406 of this issue. The others will follow in early issues of This Journal.

It is believed that there is now enough operating experience to justify the statement that considerably higher unit loads can be safely applied to two major parts of sewage treatment plants. These are the facilities required for treatment by the activated sludge process and those required for the digestion of sludge. For each part, so-called conventional or standard unit loads have been stated in manuals of State Health Departments and are used extensively today in sewage treatment and sludge disposal design.

In the case of activated sludge treatment, conventional design is illustrated by a displacement period of mixed liquor of about 6 hr, with a mixed liquor suspended solids of about 1,500 ppm or more, and a daily load of 25 to 30 lb of applied BOD per 1,000 cu ft of aeration tank (1). By modifying the operational design, the size of the aeration tanks may be reduced as much as 60 per cent without lowering treatment efficiency (2).

In the case of sludge digestion, conventional design may be illustrated by a unit load of 2.0 to 3.0 lb of applied solids per cubic foot of tank volume per month. Improvements in operational design may permit an increase of about three times these loadings.

It is emphasized that facilities for activated sludge and sludge digestion are but parts of a treatment plant and, as such, can be affected by imperfections in other portions of the plant. For example, inability to remove solids when required, as a result of improper functioning of final settling tanks, may cause a good aeration system to be ineffective. Faulty screening or grit removal may make digester operation more difficult. Reliable methods of ultimate sludge disposal are essential for all elements. Sewage characteristics may vary greatly in different locations. The effects of climate, the required degree of treatment, and possibilities for final sludge disposal must be considered. In summary, consideration must be given to the proper relation of the various plant elements as well as variations in sewage and external factors.

True advances in practice are often slow in development and result from much experimentation and in refinements based on actual operating ex-

* Presented at the 31st Annual Meeting, Federation of Sewage and Industrial Wastes Assns.; Detroit, Mich.; Oct. 6–9, 1958.

perience. Performance under full-scale operation is the ultimate test. A treatment process must be stable, susceptible to simple control, and provide easy maintenance of equipment. Operating routines should be simplified to the maximum possible extent. Stability of results and in operating procedures are necessary for any soundly designed process.

Sludge Age

The basis for improvements in methods of treatment by activated sludge is to be found in a better understanding of the fundamental process. The basic principles are quite simple. Under aerobic conditions, a well-conditioned activated sludge will abstract the suspended, colloidal, and soluble organics from sewage in 30 min or less. The abstracted materials are attached to the mass of activated sludge, but portions of them, particularly those synthesized from the soluble organics, have poor settling qualities. To avoid excessive carry-over of poor settling material into subsequent phases of the process, it is necessary to subject them to a prolonged period of aerobic biological action, sufficient to alter their physical properties so that they will settle readily. It has been found that the freshly abstracted materials must be held in the aeration system, on the average, for 3 to 4 days. This consideration led to the "sludge age" theory (2)(3).

For practical operating control, it is necessary to relate the mass of solids in an aeration tank to the incoming load so that the sludge will maintain its ability to treat the sewage while retaining good settling qualities in the final tanks. One method is to divide the weight of the solids in the aeration tank by the daily weight of incoming suspended solids to give a sludge age in days. This is convenient, as the determination can be made in a few hours. Its accuracy as a measure of time will vary with the composition of the sewage. Perhaps 20 to 30 per cent of the solids are destroyed by prolonged aeration. This is counterbalanced, in part, by the conversion of soluble BOD to suspended solids that are not recorded as incoming suspended solids. Where the numerical values of BOD and suspended solids are about equal, the suspended solids figure should closely approach the true sludge age. Where there are high values of soluble BOD, it is better to base the solids level in the aeration tanks on the basis of the load of the incoming BOD rather than that of the suspended solids. Within the range of Haseltine's recommendations (4) it was suggested that there should be 100 lb of aeration tank solids for every 30 lb/day of applied BOD load. This is equivalent to a 3.33-day BOD sludge age and is basically the same criterion.

Application of Sludge Age

In the applications of the principles outlined above to the conventional activated sludge flow pattern, it will be found that, with normal sewage strengths and other usual procedures, the aeration period will approach the six hours called for in many design guides. If, however, part of the aeration tank is devoted to the aeration of sewage and sludge mixtures at solids concentrations higher than that of the aeration tank effluent, the requisite mass of solids can be kept in the system, the same effluent concentration maintained, and satisfactory performance accomplished with tanks of much smaller volume.

Step Aeration

The first application of these principles was in the step aeration method (5), first used in the Tallmans Island Plant in New York City in 1939. Since then, New York has built or revised six other plants incorporating this principle. The usual New York City aeration tank has four passes, or

channels. Return sludge flows through all passes in series, and sewage may be added, in the proportions desired, at the head end of any or all of the passes. The greatest air demand occurs when sewage comes in contact with the sludge; therefore, to equalize air use, sewage is applied to as many passes as practicable, consistent with the tank volumes available and the effluent concentration desired. Should the sludge index begin to deteriorate, sewage inlet gates are adjusted to shift the sewage application toward the effluent end. This reduces the effluent concentration so that the more voluminous sludge occupies no more space than the sludge of better quality, and it is therefore not necessary to adjust the rate of sludge return. This procedure simultaneously increases the time of sludge reaeration and usually results in a restored sludge index.

This is in marked contrast to the early years of operation at the Wards Island Plant, under the more rigid pattern of the conventional flow sheet, when a downward spiral of deteriorating results sometimes occurred. When deterioration occurred, sludge would occupy more space in the final tanks. Increased return rates for the more voluminous sludge would lower sludge concentrations and the detention time in the aerators, resulting in further impairment of sludge quality. The continuation of this course would eventually require the bypassing of part of the load or the wasting of solids from the system prior to starting anew. Since the installation of step aeration and the modification of the final tanks, average flows 25 per cent above design capacity have been treated readily, while using only one-half of the aeration tanks. Effluents have been as good or better and of more uniform quality than those secured under the original system.

While step aeration is the earliest of the complete processes that permit a large reduction in aeration tank volume, there are other methods being used in full-scale operation. These include the Biosorption method (6), developed at Austin, Texas, another method discussed by Eckenfelder and O'Connor (7), and the methods developed by Kraus at Peoria (8).

Biosorption

The Austin development was an interesting solution to a difficult problem. From its performance records, the system was using a 3.5-day BOD sludge age and a sewage-sludge displacement period of 37 min. The proportions of sludge reaeration and sewage-sludge contact periods are almost identical to a step aeration installation, where all sewage is added to the fourth or last pass. If a single point is used for sewage application, there is no way to adjust for changing loads and changing sludge condition, except by the frequently cumbersome procedures of the conventional method. At the Hunts Point Plant in New York City, two passes are used for sludge reaeration and two passes for sewage-sludge contact. The quantity of air used in the latter two passes is twice that required for the sludge reaeration passes. With a sewage-sludge contact in one pass only, there may be a problem of meeting the air requirements of a sewage with a high oxygen demand. Thus, there is little margin to assure uniform results, under variable conditions.

Kraus Method

In meeting his problems at Peoria, Kraus (9) added new concepts. In addition to sludge reaeration and a short sewage-sludge contact period, he added digested sludge to the activated sludge being reaerated. The digested material, with part of the volatiles destroyed by anaerobic action, and after a substantial period of aeration, is effective in the sewage purification

process. It adds weight to the activated sludge and results in a good sludge index and simplifies the problems of the final settling tanks. In order to meet a problem of high unit air use economically, this procedure supplied air to both sides of an aeration tank. This method needs confirmation for application to sewages and problems less difficult than at Peoria, but where effluent standards must be higher.

Air Considerations

The volume of air required for the activated sludge process is related to the amount of BOD to be removed. It also appears that relatively more air is required to remove those parts of the BOD that are soluble, as this is done by incorporation in biological structures. There are also practical limits to the amount of air that may be usefully applied per linear foot of aeration tank. When unit demands are high, this may be a limitation on the extent to which aeration tank volume may be reduced.

The efficiency of air use may be influenced by the type and location of diffusion media. Quite aside from these considerations, however, there is a clear indication that, as the BOD loading per unit volume of aeration tank is increased, there will be a corresponding increase in the efficiency of air utilization. This is not a straight line function, but, as suggested by Torpey (10), varies more nearly as the reciprocal of the square root of the unit BOD loading. For example, if the unit BOD loading is increased four times, the air use per pound of BOD may be halved. The use of methods to accomplish the same work in tanks of smaller size would thus have merit, not only in the reduction of capital costs, but also in reduced operating costs for air compression.

Settling Tank Design

The effectiveness of any aeration system, be it conventional or any of the modifications mentioned above, is dependent on the effectiveness of the final settling tanks. The separation of the large mass of flocculent activated sludge carried by the mixed liquor bears no relation to the separation of the more granular solids in the primary tanks. These flocculent solids quickly unite to form density currents that flow along the tank bottom with a velocity of 5, or more, fpm. An obstructing wall will deflect them upward and cause them to return, at a slower rate, along the surface. The volume of the flowing sludge blanket may be 25 per cent or more, at index concentration, of the sewage being treated. The usual type of collector mechanism does not have the capacity to handle this volume, therefore the removal of sludge from the tank is dependent on hydraulic flow. In circular tanks, with the sludge outlet at the center, the time required for the removal of some of the sludge is unduly long. As a result of this tendency there is equipment on the market designed to minimize this effect. In such tanks the effluent weirs must be carefully located to avoid the effect of the upturn of the density currents. Similarly, in rectangular tanks, the point of sludge withdrawal should be placed at mid-tank, or beyond, so that the sludge will flow to it under its own weight, and without too much dependence on the removal mechanism.

The burden on the final tanks is proportional to the mass and condition of the solids that pass through them. Thus, the concentration of solids in the aeration tank effluent, the sludge index, and the rate of sludge return all have a bearing on the performance of any particular final settling tank. The aeration system must be proportioned to hold the requisite mass of activated sludge, but

the sludge concentration of the aeration effluent is limited by the form and utility of the final tanks.

Digester Design

Advances in sludge digestion, as is true in treatment by activated sludge, have been based on a clearer understanding of fundamental considerations. Pilot plant work by Torpey (11), and Morgan (12), and laboratory work by Sawyer *et al.* (13), among others, make it clear that the rate of activity of anaerobic biology, under controlled conditions, is rapid and quite comparable to aerobic organisms. In the past, this fact has been masked by the nature of the structures provided for sludge digestion and by the character of the materials to be digested. The material going to digestion tanks includes some substances that will float and others that will sink. Of the floating materials, including greases, only part are capable of being digested, and the remainder will collect at the surface in the form of a scum blanket. There usually are large areas of tank bottom left essentially undisturbed by sludge removal operations. In these areas, sludge is deposited and permitted to consolidate to form inert masses which actually reduce tank capacity. It is reported that the loss of effective digestion capacity from these two causes often amounts to two-thirds of the original tank volume.

Torpey (11), Morgan (12), and Sawyer *et al.* (13) have shown that nearly 90 per cent of the total possible gas production can be expected during a 6-day digestion period. This is not the basis for design, but is an indication of the rate of activity. Actual tank volumes required to provide a specific displacement period depend on the concentration of the applied sludge. Thus, in efforts toward better use of digestion tank volumes, the use of specially designed sludge thickening tanks is becoming more common.

Recommendations for Improvements

The requirements for the best utilization of sludge digestion tank volumes and hence a much smaller installation, may be summarized as follows:

1. The maintenance of uniform temperatures near 90°F.
2. The maintenance of alkalinity in excess of 2,000 ppm, which will occur naturally with the denser raw sludges.
3. The feeding of raw sludge as continuously as practicable, to keep the bacterial population at uniformly high levels.
4. The thickening of raw sludge to maximum feasible concentrations up to 10-per cent solids—beyond this concentration the sludge becomes difficult to handle.
5. The provision of means for the prevention of dense scum blankets. This means periodic removal of top scum, or its incorporation in the mass of digesting sludge.
6. The provision of means for preventing bottom deposits, either by multiple outlets or by induced currents.
7. The circulation of the contents within the digester to distribute fresh solids quickly throughout the tank.

Meeting the requirements listed above will permit the safe loading of a primary digestion tank with raw solids at a rate of over 8 lb/cu ft of tank volume per month. This is three or more times the loading previously considered suitable.

New Considerations

The essential new considerations involved in improvements in sludge digestion are the methods of assuring substantial homogeneity of the tank contents, thus making the best use of the space that is available. There are a number of available devices that

have been designed for this purpose. Some are proprietary and others are not.

One good example, in the latter category, is in the primary digesters of the Nut Island Plant in Boston. Here, the two 108-ft diameter tanks are each provided with four 2-in. nozzles fixed to a tank cover above the water surface. About 1,000 gpm of digester liquor is circulated through the four nozzles, impinging on the scum layer in such a manner as to cause a rotation of the tank surface. As a result, the scum layer is kept in a soft and fluid condition. Periodically, the undigestible scum, which has accumulated, is drawn off through pipes. This is possible because of the fluid condition of the scum. Each tank is provided with four points of sludge withdrawal, so that bottom deposits are minimized. While these tanks now operate at about half the safe loadings suggested above, there is every indication that they could handle the higher loadings, particularly if the applied raw sludge were at higher concentrations.

There are a number of proprietary devices available for better tank utilization, some of which have yet to be proved by extended operating experience. Among these devices is a draft-tube mixer.* This unit draws the scums and liquor from the top, in large volumes, and discharges the flow near the bottom in such a way as to keep the bottom sludge agitated and in motion. Scum layers are removed and the undigestible scum is kept mixed with the tank contents and passes off with the digested sludge. The mixing within the tank is thorough. A limited range in water level is important for the best operation of these units.

Another device† forces digester gas through diffuser tubes in the center of the tank near its bottom. The rising gas creates currents vertically upward in the center, radially outward at the top along the water surface, downward at the side walls, and across the bottom to the center. These currents bring about a good mixing of the tank contents and tend to minimize bottom deposits.

An air lift, operated by digester gas‡, is placed in the center of the tank, and causes a similar pattern of circulating currents.

Another system§ also uses compressed digester gas as the moving force. In this method, gas is injected at a moderate depth at several points spaced over the tank area. At each point there is a rising current with horizontal dispersion at the top. It is reported that these currents result in adequate mixing in the upper part of the tank and reduce scum formation near the points of gas application.

None of the devices using gas for digester mixing make provision for the removal of that part of the scum which will not digest. Supplementary means may be required for this operation.

When primary digestion tanks are operated with concentrated raw sludges, the effectiveness of secondary digestion is greatly diminished. If the maximum of liquor is extracted from the raw sludge, by sludge thickening methods, it is found that very little more can be decanted from the secondary digestion tanks. This is particularly true if solids from secondary treatment are present. Secondary digesters lose effective capacity from the accumulation of undigestible scums and bottom deposits. Agitation to correct these conditions will preclude any possibility of further liquid sepa-

* Manufactured by Dorr-Oliver Inc., Stamford, Conn.

† Manufactured by Chicago Pump Co., Chicago, Ill.

‡ Manufactured by Walker Process Equipment, Inc., Aurora, Ill.

§ Manufactured by Pacific Flush Tank Co., Chicago, Ill.

ration. As a possible alternative, smaller storage tanks may be substituted for secondary digestion tanks, depending on operating circumstances and on the method of final sludge disposal.

Summary

Current practice in sewage disposal, as acceptable to control agencies such as state health departments, is outlined in standards established by many such departments. As brought out in this discussion, many of these standards recommend the sizes for aeration tanks to be more than twice as large and digestion tanks to be more than three times as large as are necessary under today's well established methods and principles of design and operation. While existing standards serve a useful purpose, there is always the danger of their tendency to limit imagination and initiative in design practice. However, regulatory agencies have generally given sympathetic consideration to the use of advanced practices.

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ECONOMICAL PRACTICES IN SEWAGE TREATMENT PLANT CONSTRUCTION*

By Alfred W. Sawyer

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This is one of four papers collectively forming a sewage treatment cost reduction symposium. Others deal with activated sludge and digestion processes, operation, and over-all regulatory considerations. The paper on activated sludge and digestion processes appears on page 399 of this issue. The others will follow in early issues of This Journal.

Sewage treatment plant construction is usually expensive and the present trend toward better treatment of wastes in order to preserve the nation's health and conserve its natural resources is slowed by high costs. There is no magic formula for reducing these costs. Therefore, most of this paper will be limited to a review of some of the real approaches that can be made to the problem.

Preliminary Planning

Careful planning by both the engineer and the contractor can do much to reduce the costs, but it should be recognized that the cost is substantially determined before the contractor moves onto the job.

Construction cost starts at the designer's desk and on the drafting board. Before the treatment plant can be designed it is necessary to know what job is to be done, what area is to be served, and what is to be treated, both as to quantity and constituents.

Domestic wastewater is fairly well fixed as to character, with the exception of the recent complications caused by detergents and garbage grinders. Industrial wastes, on the other hand, cover a wide range both as to quantity and quality, and they may change frequently and rapidly, owing to changes in industrial processes, and/or daily operational fluctuations. In some municipal sewer systems industrial flows are minor in quantity and strength, while in others, they assume major proportions.

Sewer System

If the wastewater treatment plant is to perform its proper functions, a careful study of the load to be handled is needed, including the best possible estimate for the future. If there are existing sewers, general review of their condition and the flows they carry is important. It is helpful to know whether there is excessive infiltration, or whether there are so-called bootleg storm drainage connections into sanitary sewers. The construction cost of capacity to treat flows that should never be allowed to reach the treatment plant frequently is more than the cost of eliminating major offenders. In addition, treatment of such flows is a continuing expense.

* Presented at the 31st Annual Meeting, Federation of Sewage and Industrial Wastes Assns.; Detroit, Mich.; Oct. 6–9, 1958.

Therefore, it is better to investigate the possibility of eliminating the source of excess flow rather than to provide treatment facilities for it. There is a parallel to this in the water industry. Many water supply systems have, in effect, realized substantial increases in the capacity of their supply works by reducing the amount of unaccounted-for water in the distribution system. The same reasoning applies to the wastewater end of the cycle.

Industrial Wastes

Next in the review of flows to be handled are the industrial contributions and any other unusual loads. At this point a review of the existing sewer rules and ordinances is in order. It is desirable to know whether they are up-to-date and whether they will cover conditions prevailing when the plant is placed in service. Other data needed are (a) the policy toward garbage grinding, (b) whether sewer charges are set up in a manner that will insure an equitable distribution of construction and operating costs for the new plant, and (c) whether excessively low or high pH, toxic or other unusual wastes are to be expected.

Disruption of treatment plant processes by industrial wastes are not uncommon. To provide for such anticipated problems, preventive, rather than curative steps, are recommended. Planning for these problems before, rather than after, the plant is built can precipitate changes in the treatment plant needs. Frequently an industry faced with heavy charges for treatment in a municipal plant, or even in its own plant, will look to its housekeeping and find that in the drive for production the quantity and constituents of waste flows have been neglected. Occasionally it is found that valuable products or by-products are literally going down the drain together with more than the necessary amount of water, which in itself is a valuable raw material. Tightening up of processes, recovery systems, and pretreatment, including neutralization of some of the more critical wastes before discharging them to the sewer are on the increase in industry. For purposes of wastewater treatment considerations, whether this is done for economic or legal reasons is secondary if the result is a smaller and more amenable load at the treatment plant.

If industrial wastes are included in the flows to be treated, as much as possible should be determined about them and their ramifications in advance of plant design. Plant capacity built to handle industrial flows, which are later reduced to save on sewer charges, can develop into a liability, since money has been spent on this capacity and revenues are less than expected.

Type and Degree of Treatment

Next comes consideration of the degree of treatment required and this is usually set by control agencies. While much has been done toward stream classification and workable rules, much remains to be done. There are cases where a man who dips a pail of water from a stream and then pours it back breaks the law because the stream itself cannot pass the requirements set for effluents. If the dip is for one-pass condenser cooling by a large power plant, strict adherence to the law might require treatment of many million gallons per day before return to the stream.

The degree of treatment should depend on the receiving waters. The range of conditions encountered varies from discharge through an outfall into deep waters of the ocean to discharge into a small stream where, in dry weather, the effluent represents a major portion of the flow. In the latter case, the many advantages of dilution are not available and a greater degree

of treatment may be required if good conditions are to be preserved downstream during low flow periods.

Upstream works for water supply, flood control, or stream regulation can change the picture and a searching look at conditions that will prevail in the receiving waters, together with the possible effect of these conditions on the requirements set by controlling agencies, should be made.

The type of treatment always should be given careful appraisal. The favorable and unfavorable characteristics of the various types and their effect on plant costs have been, and always will be, the subject of many papers and discussions and it is a problem to keep abreast of recent developments.

Where space allows, lagoons are finding more use and acceptance. Another approach toward reducing cost is the use of "package" type plants which combine several operations in one unit.

An important requirement is to make every effort to assure that the type of treatment chosen will work. In some cases where industrial wastes are involved, pilot plant studies are useful and may even be mandatory. The most expensive plant that can be built is the one that does not work, because its cost per unit of load treated reaches infinity. A plant that is too small is also very expensive because the money has been spent and the results are inadequate. The plant that is too large represents money spent needlessly, and in addition, operation may be unwieldly and the effluent may even be inferior to that of a properly sized plant.

Reduction of plant construction cost can be carried to extremes that result in excessive operating and maintenance expense. This would be shortsighted on the part of any municipality but is sometimes found in industry where financial and tax manipulations may transcend the conventional approach.

The Plant Site

By their very nature, treatment plant sites often further the tendency toward high costs. They are relegated to low ground as an aid in getting flow to them and to get them close to the receiving waters. Being low, the plant then needs a defense against flood conditions. By being located near a body of water, foundations and ground water can be a greater than normal problem.

When an existing plant is being enlarged there is little choice of site and the only advantage is that there may be records of subsurface conditions encountered when the original plant was built. The site for a new treatment plant should be given the same careful scrutiny that most industries give to new sites. The additional costs of a longer trunk sewer might be more than offset by savings on a more desirable site. In addition, desirability for both immediate construction and future expansion should be taken into account.

Another potential advantage of a longer trunk sewer can be the increased area which can be served by the plant in the future. All too frequently the transition of farm lands into developed areas eventually extends beyond the treatment plant, and sewage collection and treatment for these areas become expensive.

When available sites and the contributing systems are studied, it may be found that pumping is necessary. In this event, a few more feet of pumping head may allow the major plant units to be set high enough to avoid the need for flood protection and to take advantage of better foundation conditions. If there are such potential advantages they must be weighed against the increased cost of pumping.

On most plant sites subsurface investigations are necessary. Sufficient borings, test pits, and samplings should be made to determine not only the line of demarcation between rock

and unconsolidated materials but the nature of these materials, including the characteristics of clays; whether or not there are boulders, ground water levels and activity; and if quicksand conditions should be expected.

All of this information is helpful to the designer and whatever is collected should be shown on the plans to aid the contractors in making fair and balanced bids without heavy additions for contingencies.

Most treatment plant structures develop relatively low unit loads on their foundations. An advantage can be taken of this effect in some cases where pile foundations might be indicated at first glance. A careful analysis of the foundation materials and their unit and differential bearing capacities, the weight of materials removed by excavation, and the manner in which the loading of new structures can be distributed may show that piles are not needed—and this can result in a major saving in cost.

Plant Arrangement

General Planning

Over-all planning and arrangement can do much to keep plant costs down. The first consideration is the principal units of the process chosen, and the second is the connections between them. Unless the two are kept in balance the cost of the latter may become unduly high. Long piping or channel connections increase the cost excessively, particularly where the process requires recycling. An attempt should be made to arrange principal plant units in a reasonably compact grouping, and yet make allowance for working room, both during and after construction, and for future expansion with short, but not cramped, connecting lines.

Before the preliminary layout of units has progressed very far, a process flow sheet is needed, and with this as a basis an inventory of the connecting lines between all units and structures should be made. In addition to main flow, returns, sludge, supernatant, and bypasses, this inventory should include heating, air, water, gas, chemical, electrical, and signal lines. When they are all considered, it may be found preferable to lengthen a large line in order to shorten a number of smaller ones.

Study will usually reveal that valves and other controls can be grouped in common pits or chambers to avoid scattered installations, each with its problems of drainage and ventilation. In many cases short pipe tunnels can be used to advantage with the numerous lines racked where they are accessible for maintenance, clean out, and repairs, and even for subsequent interconnection if future revisions in the plant process are desired.

Criss-crossing the main flow conduits and numerous smaller lines at odd angles and elevations may save on footage, but high construction costs can result. Excavation for structures and pipe lines normally is much wider than the usual limits of pay lines. It is almost impossible to leave narrow strips and fillets of unexcavated material between trenches, and as a result scattered piping can mean virtual removal and rehandling of all material over a wide area. When consideration is given to the pattern of excavation and pipe laying required and the maintenance of access necessary for construction, the extra length of pipe needed for parallel and more orderly lines often is unimportant.

Structures requiring complicated formwork may save concrete but do not necessarily save ultimate cost. Wherever possible, standardization to allow maximum reuse of forms is desirable. This can be applied by making circular tanks the same diameter and by standardizing manholes, chambers, and other smaller structures.

It has been said that a consultant is a man who tells someone else how to do something he can't do himself.

This may be true if the designer takes the attitude of "let the contractor figure it out." The contractor, in turn, will add to his prices the cost of "figuring it out."

It is usually the contractor's responsibility to determine the manner in which he will approach the work, but the designer should always have in mind a reasonable approach and recognize that the plan he draws must be translated into finished structures while contending with the whims of nature, ground water, sliding banks, and the many other problems that face the contractor.

Wet Conditions

As previously mentioned, ground water on many sites increases the cost. This is especially true for deeper structures, such as grit chambers and pumping stations. Sheeting, bracing, and dewatering are all tedious and expensive operations. There are many instances where design can allow for the use of a caisson as an alternate method of construction. Unfortunately, its possibilities are frequently ignored by the designer and not recognized by many contractors.

With moderate care and without complicated equipment, a caisson can be dredged down in wet conditions and a bottom seal of concrete placed by the tremie method, thus eliminating the need for sheeting, bracing, and pumping. Familiarity with the basic method of placing tremie concrete is a prime consideration before attempting such an operation.

Typical examples of wet caissons which have been observed are several small pumping stations with inside diameters ranging from 8 to 20 ft and depths of 15 to 27 ft, mostly below water level; a grit chamber 20 ft in diameter and 25 ft deep; and a screen well with an inside diameter of 30 ft and a total depth of 45 ft, of which 25 ft were below sea level.

Circular caisson construction is well suited to deep structures since it gives a good distribution of wall loads and simple reinforcement requirements. Extra weight is often needed to prevent floating of deep structures, and if the caisson itself is not heavy enough to accomplish this, the weight of interior partitions and fillets can be used. Tremie concrete placed under water also can be useful for deep manhole bottoms and for other small slabs in low, wet locations.

Another example of recognizing construction difficulties and designing to reduce them is in the selection of pipe for wet trenches. A pipe with joints that can be made up tight when wholly or partially submerged may cost more delivered to the trench but less when finally in place than pipe having poured or plastered joints. It always seems that the biggest problem with water is in the bottom one or two feet of trench, and this may result in hurried operations, not always successful, to get the pipe in and the joints made up before the trench floods. Therefore, laying the pipe in the water can simplify the job.

New Trends

A detailed discussion is not intended on the relative economies of various materials or shapes of structures. Many factors influence these selections, and generalizations without detailed discussion are not practical. However, there constantly appear on the market new materials and improvements of applying both new and existing materials and techniques. It is advisable to follow the trends to keep abreast of the most economical practices.

It may be mentioned that in addition to concrete and steel tanks and combinations of these materials there has been increased use of earth embankment where space and suitable soils are available. A cut and fill earth basin is inexpensive and circular basins can be equipped with conven-

tional sludge collectors. However, a moisture sealing material is advisable since some difficulties have been experienced in earth basins with no interior surface treatment. Other economical methods have included earth channels, some with light-weight, steel sheet piling sides.

Extras

The final step in the design stage is to make the plans and specifications as clear and concise as possible. If they are ambiguous, bidding contractors may either add to their prices for contingencies or put in low prices with the expectation of making up for them on extras. Obviously the latter approach is the more common in the case of competitive bidding.

A few reasonable and relatively small extras should be expected on any job to cover field changes and unusual site conditions encountered as the work progresses. The large extras are frequently of a type that could have been avoided if two or three additional borings had been taken or if a minimum of extra effort had been added to the plans and specifications.

Schedule of Construction

In scheduling construction it is often said, "We can take bids in the winter and have the contract awarded by spring so that the contractor can take advantage of the good summer weather." Unfortunately, there frequently are delays before the contract is finally signed and weeks of good weather can be lost. More important is the lack of lead time allowed the contractor after award of the contract. He must schedule his work, arrange for his subcontractors, and get material and equipment to the site. All of this takes time and the time required to process and check shop drawings is no small part of the total. Unless the job is a relatively small one the contractor may find himself just getting underway with major concrete work when cold weather returns.

For larger jobs, most contractors prefer to bid in the late fall so that the winter months can be used for organizing the job prior to a full construction schedule as spring weather permits.

In some cases where major excavation or other earth moving is involved, a separate contract for a large part of this work can be let in advance of final completion of the plans. This allows the general contractor to start concreting operations almost as soon as he moves onto the site.

Interest During Construction

The financing of sewage plant construction is a subject in itself deserving careful study and competent advice. The only phase of financing mentioned here will be interest during construction, which is just as much a part of construction cost as steel or concrete. When it is required to have the bonds sold before a contract is awarded, interest during construction can amount to a sizable percentage of the total cost. Occasionally there are cases where the bond money has been reinvested at a profit, but these are the exception rather than the rule. Where possible, the financing of construction cost through most of the job by short term notes followed by sale of the bonds near the end of the work is fairly successful in reducing interest during construction.

Construction

If the contractor's construction costs are to be kept down, the first and foremost requirement is for a good job superintendent. This does not necessarily mean a man who can get by with the smallest payroll, but one who can plan ahead and organize the work so that the right manpower and equipment are available where and when needed. If this is done, there is a

minimum of lost motion and rehandling of materials.

The superintendent also must be well versed in the labor laws and labor union matters.

The contractor usually has the option of selecting from several comparable alternates for some of the equipment items. In making his selection, it is well to weigh not only the quoted price but the other elements of ultimate cost as well. These include the manufacturer's reputation for the speed, accuracy, and thoroughness on shop drawings; for having the various pieces fit together when they are assembled; and for field service in the tune-up and adjustment stage.

Although a review of the subject of equipment for improving construction methods with economy in mind is not presented, a few examples may emphasize the importance of this consideration.

The use of electric motor-driven pumps for construction work is on the increase as a cost saver, particularly where continuous pumping is needed. In addition to conventional, centrifugal, diaphragm, and vertical pumps there are a number of submersible pumps now available ranging in capacity from a few to several hundred gallons per minute.

Conveyor belts can be used to advantage for some materials handling applications. On a recent job the contractor used a conveyor system to transport the crushed stone into two trickling filters. He was fortunate in that one side of the filters had been cut into a hill and he was able to use this for elevation from which to dump the stone into a hopper and over screens for final cleaning with gravity feed onto the belt conveyor system.

The same contractor made unusually careful layout drawings for all interior piping to permit a maximum amount of shop fabrication. Field assembly was then simple and rapid.

As a final example, a contractor devised a very good system of formwork for a circular concrete tank. Bow string trusses with double ply ¾-in. sheathing for the bow and double 2 × 4's for the chord were used as inside wales. Doubled ¾-in. sheathing also was used as the outside wales. Studs (2 × 4's) and plywood sheathing completed the form. Each truss had an arc length of approximately 30 ft and the form was moved for reuse in 30-ft long sections. An interesting sidelight is that when finished with them, the contractor sold the trusses at cost to someone who wanted them for roof trusses.

Conclusions

Effective savings in the construction cost of sewage treatment plants are primarily functions of careful planning and design. The quantity and character of flows to be treated should be known and this is of particular importance when industrial wastes are involved.

Careful selection of the plant site and the arrangement of units on the site can save money, particularly where foundations may be a problem.

Design should recognize site conditions and the manner in which these conditions can be met efficiently by the contractor. The designer also must keep abreast of new developments and determine if they can be applied to the case at hand.

Simple and functional design not only saves construction costs, but excessive operation and maintenance costs as well. "Gingerbread" may look fine on the day the plant is dedicated, but it has no place in a sewage treatment plant and can become a liability later.

Throughout the planning it should be kept in mind that reducing quality to save cost is comparable to stopping the clock to save time.

CHEMICAL COMPOSITION OF THE PARTICULATE FRACTIONS OF DOMESTIC SEWAGE *

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Information in the literature regarding the organic constituents of sewage is meager. Buswell and Neave (1) reported on the soluble nitrogenous constituents of raw sewage. Pillai *et al.* (2) gave a detailed analysis of the individual amino acid in raw sewage. Finally, Wuhrmann (3) gave some analyses of the nitrogen content of Zurich sewage.

It has been generally recognized that proteins, carbohydrates, and fats exist in sewage, but little is known as to the specific nature of these primary organic constituents. More detailed information than is at present available regarding the specific chemical identity of the primary organic constituents is needed.

This paper reports on the organic composition of the insoluble fraction of sewage in addition to the inorganic constituent of the insoluble, as well as the soluble fractions. The insoluble fractions of sewage solids have been considered in three groups: (a) the colloidal, (b) the supracolloidal, and (c) the settleable fractions. An attempt will be made to show whether there are seasonal variations in the chemical composition of sewage.

Methods and Procedure

Sewage was collected from a single municipal plant treating principally domestic sewage. The sewage was average strength. The samples were screened through a No. 20 sieve. All sewage samples were taken between 9 AM and 4 PM from Monday through Friday.

The winter composite, taken from December 1 to January 26, consisted of 11 individual samples totaling 100 liters. The volume of sample was proportional to the flow. The sampling schedule was arranged so that each hour of the day would be properly represented by the composite.

The summer composite, collected from June 4 to September 8, consisted of 24 grab samples of 6 liters each. No samples were collected during periods of high flow caused by rain. In this case both the hours of the days and the days in the week were staggered and equally represented in the composite. A separate composite sample was collected during these months for mineral analysis because the necessary addition of reagents to the samples for organic analyses made these samples unsuitable for mineral analysis.

Choice of the method of separation (4) of the particulate matter in sewage required (a) the separation to be accomplished within a few hours to minimize the changes caused by bacterial action, and (b) a quantitative evaluation of the recovery of the particulate fraction.

After the separation of the settleable solids by the technique described in "Standard Methods" (5), the supernatant was centrifuged with a continuous feed, high-speed centrifuge † operated at 14,000 rpm at a

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† The Sharples Corporation, Philadelphia, Pa.

flow rate of 100 ml/min. The solids removed were designated as supracolloidal and consisted of particles 0.1 to 1 μ in diameter. The colloidal fraction was quantitatively separated from the dissolved solids by filtration through a cellulose ultrafilter membrane under a pressure of 800 psi of nitrogen gas.

The three particulate fractions collected from individual sewage samples required one hour to dry at room temperature in front of a circulating fan. The solids content of the particulate sewage fractions, calculated from the air-dried weights, contained about 10 per cent moisture. It was considered preferable to accept this margin of error rather than subject the samples to oven drying at 105°C with possible consequent effects on the organic matter. The supracolloidal fraction was removed from the bowl of the centrifuge with a minimum of distilled water. The pH was reduced to 3.5 and flocculated and centrifuged at 2,000 rpm, after which the residue was air-dried as above.

The rate of filtration through the membrane was 250 to 300 ml/hr. After filtration the colloidal solids were removed from the membrane, suspended in water, and precipitated with ferric chloride; the solids were then centrifuged and air-dried.

The dried particulate fractions from each grab sample were pooled for a composite and kept refrigerated until ready for analysis.

Details of analytical methods employed in this study have been reported previously (6).

Results

Solids

The total solids in the various fractions of the individual samples which were used for the summer composite are not presented.

The analysis of the data in terms of hours and days of collection shows: (a) that variation in total solids concentration of the raw sewage is generally due to variations in the dissolved solids, (b) that there is an apparent relationship between sewage flow and total solids concentration, (c) that the sewage flow is consistently higher on Monday than on any day from Monday to Friday, and (d) that total solids concentration is usually highest at noon. Since the sewage flow time to the treatment plant is approximately four hours, the noon peak in total solids represents morning household activity.

Analysis of the variations in the various particulate fractions of the individual samples shows: (a) that the relative amounts of colloidal and supracolloidal solids in raw sewage increase and decrease simultaneously, the colloidal fraction constituting 4.8 to 10.3 per cent, and the supracolloidal fraction representing 6.5 to 16 per cent of the total solids; and (b) that an inverse relationship apparently exists between amounts of dissolved and settleable solids. The percentage of total solids contributed by the dissolved solids varied from 42.6 to 76.6 per cent.

Table I shows the results of the analysis of total solids of various fractions used for the summer composite. The dissolved solids constitute 64.4 per cent of the total dry solids of the raw sewage and the particulate matter represents 35.8 per cent. The particulate matter is made up of 16.8 per cent of settleable solids, 11.8 per cent of supracolloidal solids, and 7.2 per cent of colloidal solids. The volatile solids as per cent of the dry solids was high in the particulate fractions (between 78.0 and 83.0 per cent) but was only 20 per cent in the dissolved fraction. Despite this, the volatile solids concentration in the dissolved fraction is higher than that in the supracolloidal and colloidal fractions and equal to that in the settleable solid fraction.

TABLE I.—Solids Composition in the Particulate Fractions of Sewage*

Item	Total	Settleable	Supra-colloidal	Colloidal	Dissolved
Total solids in various fractions (ppm)	500	84	59	36	321†
Individual fractions as per cent of total solids	—	16.8	11.8	7.2	64.4
Volatile solids as per cent of total solids in each fraction	41.4	78	83	81	20
Volatile solids in each fraction (ppm)	207	65	49	29	64

* Average of 24 grab samples taken from the same plant at different hours of the day (9 AM to 4 PM) and different days of the week (Monday through Friday) from June to September.

† Calculated value obtained by difference between the sum of individual components and total solids in whole sewage.

Minerals

The fixed solids from the individual sewage fractions of the summer composite were analyzed for 14 cations and anions (Table II). No distinction was made as to whether the elements reported were in organic or inorganic form.

The 20 ppm of chloride in the raw sewage (all in the dissolved fraction) accounts for 21 per cent of the fixed solids in sewage.

Silicon is one of the more abundant elements, amounting to a total of 3.93 ppm in the sum of all the fractions, 84.7 per cent of which was in the settleable fraction. Silicon constituted 50 per cent of the mineral content of this fraction.

There was 0.77 ppm of iron in sew-

TABLE II.—Concentration of Mineral Constituents of Sewage Fractions

Element	Sewage Fractions (ppm in raw sewage)				Sum of Fractions
	Settleable	Supracolloidal	Colloidal	Dissolved	
Cl	—	—	—	20.0	20.1
Si	3.33	0.416	0.11	0.07	3.93
Fe	0.348	0.105	0.168	0.149	0.770
Al	0.075	0.035	0.015	0.007	0.132
Ca	0.512	0.300	0.857	8.15	9.82
Mg	0.415	0.24	0.19	9.46	10.31
K	0.20	0.19	0.10	5.43	5.92
Na	0.18	0.10	0.16	22.8	23.2
Mn	0.12	0.007	0.015	0.33	0.47
Cu	0.113	0.037	0.082	1.33	1.56
Zn	0.086	0.059	0.214	<0.04	0.359
Pb	0.30	0.067	0.11	<0.05	0.48
S	0.046	0.12	0.18	10.0	10.3
P	0.55	0.99	0.57	4.45	6.56
Sum of elements	6.28	2.67	2.77	82.3	93.8
Mineral weight*	6.61	2.77	2.78	83.2	95.3
Recovery (per cent)†	95.1	96.3	99.9	99.0	—

* Fixed solids by a separate determination and calculated in terms of the total elemental content.

† Calculated from the sum of individual determinations and separate total fixed solids determinations.

age, nearly 45 per cent of which was in the settleable fraction. Aluminum was present in very small quantities in all the fractions and added up to 0.13 ppm in the total sewage. Calcium content of the sewage was 9.8 ppm, 83 per cent of which was in the dissolved fraction. Magnesium was similarly high (10.3 ppm) and most of it (91 per cent) was found in the dissolved fraction. Calcium and magnesium constituted 21 per cent of the fixed solids of the sewage. Potassium content of the sewage was 5.9 ppm while sodium content was 23.2 ppm; both were found most abundantly in the soluble fraction (92 and 98 per cent respectively). Potassium and sodium together represented 30 per cent of the fixed solids. Manganese content of the various fractions was low, totaling only 0.5 ppm. One and a half ppm of copper was found, mostly in the soluble fraction. Small amounts of zinc and lead were found in the various fractions. Total sulfur was present to the extent of 10 ppm, practically all of it in the soluble fraction. The concentration of phosphorus was 6.56 ppm, nearly 70 per cent of it in the soluble fraction.

The sum of the elements in the various fractions checked closely with the fixed solids content, indicating that no elements of importance were left out.

Grease

The results of the analyses of the various components of the ether-soluble fraction in the different particulate fractions of the summer composite are given in Table III. A total of 45 ppm of grease was found nearly equally divided between the three particulate fractions. However, over 51 per cent of the dry matter in the colloidal fraction was due to grease. In the settleable and supracolloidal fractions, grease constituted 19 and 24 per cent of the respective dry solids, but in the colloidal fraction it constituted 51.5 per cent of the dry solids. The most abundant component of the grease in all three fractions was saturated glyceride fatty acids. The next two important components of

TABLE III.—Organic Constituents of Sewage Fractions in Summer Composite—Total Grease

Organic Constituent	Sewage Fractions						
	Settleable		Supracolloidal		Colloidal		Sum*
	ppm†	per cent‡	ppm†	per cent‡	ppm†	per cent‡	ppm†
Saturated free fatty acids	0.38	0.48	0.54	1.01	0.56	1.66	1.48
Unsaturated free fatty acids -oleic acid	0.08	0.10	0.12	0.22	0.12	0.36	0.32
Saturated glyceride fatty acids	7.94	9.95	6.74	12.54	11.20	33.43	25.88
Unsaturated glyceride fatty acids -oleic acid	2.49	3.12	1.68	3.13	1.22	3.62	4.84
linoleic acid	—	—	—	—	0.34	1.03	1.37
Phospholipids	0.00	0.00	0.08	0.14	0.10	0.29	0.18
Unsaponifiable	2.22	2.78	2.42	4.51	2.30	6.87	6.94
Sum of constituents	13.11	16.43	11.58	21.55	15.84	47.26	40.53
Total grease	15.27	19.13	12.82	23.85	17.25	51.48	45.34
Recovery (per cent)	86.0		90.0		91.8		89.5

* Total concentration of constituent contributed by the combined settleable, supracolloidal, and colloidal fractions.

† Concentration contributed to raw sewage by the respective fractions.

‡ Based on dry matter of sewage fraction.

TABLE IV.—Organic Constituents of Sewage Fractions in Summer Composite—Nitrogenous Matter After Acid Hydrolysis

Amino Acids	Sewage Fractions												Sum[a]
	Alcohol-Insoluble						Alcohol-Soluble						
	Settleable		Supra-colloidal		Colloidal		Settleable		Supra-colloidal		Colloidal		
	ppm[b]	per cent[c]	ppm[b]	per cent[c]	ppm[b]	per cent[c]	ppm[b]	per cent[c]	ppm[b]	per cent[c]	ppm[b]	per cent[c]	ppm[b]
α-Alanine	1.09	1.36	2.13	3.96	0.81	2.41	0.21	0.26	0.13	0.25	0.05	0.15	4.42
Cystine	0.63	0.79	1.21	2.25	—	—	—	—	0.06	0.11	—	—	1.90
Aspartic acid	1.06	1.33	1.96	3.65	1.00	3.00	0.15	0.19	0.05	0.09	0.07	0.21	4.29
Glutamic acid	1.70	2.12	2.43	4.52	0.65	1.94	0.18	0.23	0.07	0.13	0.14	0.42	5.18
Glycine	0.75	0.94	2.18	4.06	0.33	0.98	0.06	0.08	0.04	0.07	0.03	0.09	3.39
Histidine	1.17	1.46	—	—	0.65	1.94	0.14	0.18	—	—	0.07	0.21	2.03
Leucines and phenylalanine	1.88	2.35	2.20	4.10	0.77	2.29	0.35	0.44	0.12	0.23	0.10	0.33	5.42
Lysine	—	—	1.40	2.60	—	—	—	—	0.04	0.07	0.04	0.12	1.48
Methionine and valine	1.40	1.75	1.68	3.13	0.72	2.14	0.28	0.35	0.06	0.11	0.07	0.21	4.21
Serine	1.07	1.34	0.61	1.14	—	—	0.09	0.10	0.03	0.06	0.03	0.09	1.83
Threonine	0.67	0.84	0.75	1.40	0.19	0.57	0.11	0.14	0.03	0.06	—	—	1.75
Tyrosine	1.40	1.75	0.47	0.87	—	—	—	—	—	—	—	—	1.87
Unidentified amino acids[d]	1.05	1.31	1.87	3.48	0.72	2.14	—	—	—	—	—	—	3.64
Sum of amino acids	13.87	17.34	18.89	35.16	5.84	17.41	1.57	1.97	0.63	1.18	0.60	1.83	41.50
Total nitrogenous matter[e]	17.70	22.15	23.29	43.40	7.29	21.75	2.32	2.93	0.97	1.75	0.95	2.85	52.52
Total nitrogen due to amino-N (per cent)	78.5		81.0		80.3		68.3		65.0		64.7		—

[a] Total concentration of constituent contributed by the combined settleable, supracolloidal, and colloidal fractions.
[b] Concentration contributed to raw sewage by the respective fractions.
[c] Based on dry matter of sewage fraction.
[d] Unidentified amino acids, calculated in terms of their leucine equivalent.
[e] Total nitrogen × 6.25.

grease were the unsaturated glyceride fatty acids and the unsaponifiable matter. Saturated and unsaturated free fatty acids and phospholipids were present only in low concentrations.

Analyses were made for cholesterol in each sewage fraction but no measurable amount was obtained. This component is likely to be present in the soluble fraction.

The sum of the constituents of the various grease components analyzed gave recoveries varying from 86 to 92 per cent of the total grease in the different fractions.

Nitrogenous Matter

The organic nitrogenous material in the three fractions was hydrolyzed with acid, and the amino acid contents of the alcohol-soluble and alcohol-insoluble fractions were determined by paper chromatographic and spectrophotometric methods. Fourteen amino acids were found in the various fractions (Table IV). There were one or two spots on some of the chromatograms that gave a positive ninhydrin reaction; although they could not be positively identified and are so reported, they were recorded as though they were leucine.

The amino acids in the various fractions totaled 41.5 ppm, while the total nitrogenous matter was 52.5 ppm. The amino acids accounted for 65 to 81 per cent of the total nitrogenous matter in the different fractions. The hydrolyzed amino acids were most abundant in the alcohol-insoluble fraction. The settleable and supracolloidal

TABLE V.—Nitrogen Distribution After Acid Hydrolysis of Nitrogenous Matter

Sewage Fraction	Alcohol-Insoluble Matter (% of total nitrogen)				Alcohol-Soluble Matter (% of total nitrogen)			
	Amino-N	NH_3-N	Humin-N	Non-amino-N*	Amino-N	NH_3-N	Humin-N	Non-amino-N
Settleable	78.5	5.2	6.7	10.6	68.3	12.7	9.4	9.6
Supracolloidal	81.0	4.2	5.1	10.7	65.0	15.0	8.6	11.4
Colloidal	80.3	4.1	5.3	10.3	64.7	16.1	8.5	10.7

* Total nitrogen − (amino-N + NH_3-N + humin-N).

fractions in the alcohol-insoluble matter contained appreciably greater concentration of amino acids than did the colloidal fraction. The concentration of individual amino acids was generally less than 2 ppm in any of the fractions. The amino acids in the supracolloidal fraction constituted 35 per cent of the dry matter in that fraction while in the settleable and colloidal fractions they represented about 17 per cent of the respective dry matter contents of these fractions. Generally, the same amino acids occurred in all the insoluble fractions of sewage solids. Alanine, aspartic acid, glutamic acid, leucine, phenylalanine, methionine, and valine were present in relatively large amounts in all the fractions. The absence of arganine is notable.

The nitrogen balance of the alcohol-soluble and alcohol-insoluble matter in the different particulate fractions of the summer composite sewage is presented in Table V.

In the analysis of nitrogenous matter for amino acids, the formation of humin and the presence of ammonia in the hydrolysate made it necessary to analyze for humin nitrogen and ammonia nitrogen for the purpose of making a nitrogen balance. The difference between total nitrogen and the sum of the amino, humin, and ammonia nitrogens was considered arbi-

TABLE VI.—Organic Constituents of Sewage Fractions in Summer Composite—Carbohydrates and Miscellaneous Alcohol-Soluble Matter*

Organic Constituent	Sewage Fractions						
	Settleable		Supracolloidal		Colloidal		Sum†
	ppm‡	per cent§	ppm‡	per cent§	ppm‡	per cent§	ppm‡
Carbohydrates:							
Pectin	0.13	0.16	0.57	0.95	0.13	0.36	0.83
Hemicellulose	2.60	3.1	1.40	2.4	0.74	2.1	4.74
Cellulose	11.8	14.2	1.32	2.2	0.68	1.9	13.8
Lignin	5.12	6.1	3.28	5.6	0.86	2.4	9.3
Sum of constituents	19.6	23.6	6.57	11.2	2.41	6.8	28.6
Miscellaneous alcohol-soluble matter*	6.16	7.71	2.58	4.80	2.49	7.45	11.23

* Exclusive of grease and alcohol-soluble nitrogenous matter.

† Total concentration of constituent contributed by the combined settleable, supracolloidal, and colloidal fractions.

‡ Concentration contributed to raw sewage by the respective fractions.

§ Based on dry matter of sewage fraction.

trarily to be non-amino nitrogen. This may or may not be true. The value of non-amino nitrogen may simply represent the accumulation of errors.

A comparison of the amino acids between summer and winter composites (not presented) show that they are present in larger amounts in the summer than in the winter.

Carbohydrates

The carbohydrate components of the various particulate fractions of sewage (summer composite) are given in Table VI. Pectin, hemicellulose, cellulose, and lignin were identified and determined. These components amounted to 28.6 ppm in the three particulate fractions. The greatest amount of carbohydrates was present in the settleable fraction (19.6 ppm), constituting 23.6 per cent of the dry matter of this fraction. Of the four carbohydrates determined, cellulose and lignin were present in the greatest amount in the settleable fraction (14.2 and 6.1 per cent, respectively, of the dry matter of this fraction). The quantity of carbohydrates, as a whole, and of cellulose, lignin, and hemicellulose, in particular, in the supracolloidal fraction is intermediate to those in the settleable and colloidal fractions.

The comparison of the carbohydrates in the supracolloidal and colloidal fractions in the summer and winter composites is given in Table VII (results for the settleable fraction are not available for winter composites). The table shows that changes in the season do not alter the relative amounts present in the same fractions. The over-all concentration of carbohydrates in the two fractions is about twice as great in the summer as in the winter. One notable exception to the similarity between the composition of the winter and summer samples is the pectin content. The summer fractions contribute about ten times the amount of pectin to raw sewage as the winter fractions, the major portion being present in the supracolloidal fraction. Increased consumption of fruits in the summer is undoubtedly the contributing factor.

Table VIII represents a recapitulation of the results reported in Tables III, IV, and VI on the basis of the total greases, nitrogenous matter, and carbohydrates in the three particulate fractions. In Table VIII are also included the volatile solids values in the different fractions of the sewage reported in Table I. The individual components of various types of organic matter in the three particulate fractions totaled 138 ppm, while the

TABLE VII.—Comparison of Various Carbohydrate Fractions in Winter and Summer Composites

Constituent	Sewage Fraction							
	Supracolloidal				Colloidal			
	Winter		Summer		Winter		Summer	
	ppm	per cent	ppm	per cent	ppm	per cent	ppm	per cent
Pectin	0.06	0.21	0.57	0.95	0.01	0.05	0.13	0.36
Hemicellulose	0.63	2.3	1.40	2.4	0.37	2.0	0.74	2.1
Cellulose	0.97	3.6	1.32	2.2	0.36	2.0	0.68	1.9
Lignin	1.26	4.6	3.28	5.6	0.41	2.2	0.86	2.4
Sum of constituents	2.92	10.7	6.57	11.2	1.15	6.3	2.41	6.8

TABLE VIII.—Recapitulation of Organic Components of the Particulate Fractions of Sewage from Summer Composite

Component	Sewage Fraction						
	Settleable		Supracolloidal		Colloidal		Sum
	ppm	per cent	ppm	per cent	ppm	per cent	ppm
Total grease	15.27	19.13	12.82	23.85	17.25	51.48	45.34
Nitrogenous:							
Alcohol-insoluble	17.70	22.15	23.29	43.40	7.29	21.75	48.28
Alcohol-soluble	2.32	2.93	0.97	1.75	0.95	2.85	4.24
Carbohydrates	19.60	23.60	6.57	11.20	2.41	6.8	28.60
Miscellaneous alcohol Soluble matter*	6.16	7.71	2.58	4.80	2.49	7.45	11.23
Total organic matter†	61.05	75.5	46.23	84.9	30.40	90.3	137.7
Volatile solids‡	65.0	78.0	49.0	83.0	29.0	81.0	143.0

* Exclusive of grease and alcohol-soluble nitrogenous matter.
† Accounted for in organic analyses.
‡ Values obtained by evaporation and ignition (from Table I).

total volatile solids as determined by the evaporation and ignition of the residue was 143 ppm. Similarly, good agreements were obtained for the individual particulate fractions between the values obtained by actual determinations of the organic components and the volatile solids. The total dissolved volatile solids in the sewage was 64 ppm (Table I).

Discussion

Effect of Seasonal Variations on Sewage Composition

A comparison of the same fractions in both the summer and winter composites (Table IX) reveals that seasonal variations in domestic sewage composition are more quantitative than qualitative. The amounts of supracolloidal and colloidal solids in the summer composite were about twice as great as the amounts in the winter composite. However, the change in season did not alter appreciably the relative amounts of grease, carbohydrate, and nitrogenous matter.

Without values for the dissolved and settleable solids of the winter and summer composites for comparison, it is impossible to establish, from data collected in this study, that the summer sewage was stronger than the winter sewage. However, the higher concentrations of supracolloidal and colloidal solids in the summer sewage gives some support to the belief that it was the stronger. If it was true that the strength of sewage was greater in the summer than in the winter, the difference could not be attributed to the differences in rainfall which was 3.50 in. during the summer sampling period and 3.07 in. during the winter period. In addition, sampling was stopped during periods of rain and was not resumed until the sewage flow was back to normal.

Origin of the Sewage Fractions

A question encountered was whether the sewage fractions containing insoluble solids have the same general origin and merely represent different stages of physical degradation or whether they are of different origin, chemical composition, and susceptibility to biological decomposition. If the fractions represent sewage solids in different stages of physical degradation, each fraction should have about the same per cent of grease, carbohydrate, and nitrogenous matter. However, in Table IX when examining

the organic composition, it is seen that as the particle size of the insoluble sewage solids decreases: (a) the total grease increases from 19.13 per cent in the settleable solids to 51.48 per cent in the colloidal solids; (b) the carbohydrates, for which analyses were made, decrease from 23.6 per cent in the settleable solids to 6.76 per cent in the colloidal solids; and (c) the nitrogenous matter changes from 24.47 per cent in the settleable solids up to 45.15 per cent in the supracolloidal solids and then down to 24.60 per cent in the colloidal solids.

These changes in per cent composition with decreasing particle size in no way lend support to the hypothesis that all of the insoluble sewage solids have a common origin.

Summary and Conclusions

The primary purpose of this study was to characterize, by organic analyses, the various fractions of insoluble solids occurring in domestic sewage. Analyses were made on both winter and summer composites of municipal sewage to determine the effect of seasonal variation on the organic constituents. Separate samples were collected for mineral analysis.

The insoluble sewage solids were fractionated by settling, controlled centrifugation, and high pressure ultrafiltration into groups which were classified on the basis of particle size: (a) settleable (greater than 100 μ), (b) supracolloidal (100 to 1 μ), (c) colloidal (1 μ to 1 mμ), and (d) dissolved (less than 1 mμ). Particle-size measurements were made using an electron microscope.

From an evaluation of the collection data and solids determination for the summer composite of 24 different sewage samples, the observations are summarized herein.

Solids

1. Significant variations in the total solids concentration of the raw sewage were generally due to changes in the dissolved solids.

2. There was no apparent relationship between sewage flow and total solids concentration of the raw sewage.

3. The sewage flow was generally higher on Monday, coincident with family laundry habits, than on any other day from Monday through Friday.

4. The total daily solids concentration at the treatment plant was usually greatest at noon.

TABLE IX.—Comparison of Fractions of Winter and Summer Sewage Composites

Organic Constituent	Sewage Fraction									
	Settleable		Supracolloidal				Colloidal			
			Winter		Summer		Winter		Summer	
	ppm*	per cent†	ppm*	per cent†	ppm*	per cent†	ppm*	per cent†	ppm*	per cent†
Total grease	15.27	19.13	6.08	23.98	12.82	23.85	7.32	42.79	17.25	51.48
Carbohydrates	19.6	23.6	2.92	10.71	6.57	11.15	1.15	6.25	2.41	6.76
Nitrogenous matter‡	20.02	24.47	11.09	43.75	24.26	45.15	5.16	30.16	8.24	24.60
Miscellaneous alcohol-soluble matter§	6.16	7.17	1.49	5.93	2.58	4.80	1.70	10.00	2.49	7.45

* Parts per million in raw sewage.
† Based on dry matter of sewage fraction.
‡ Total nitrogen × 6.25.[1]
§ Exclusive of grease and alcohol-soluble nitrogenous matter.

5. Of the total solids of raw sewage, the average amount contributed by each fraction was: 17 per cent, settleable; 12 per cent, supracolloidal; 7 per cent, colloidal; and 64 per cent, dissolved.

6. The insoluble sewage solids were about 80 per cent organic and the soluble solids were 20 per cent organic.

Mineral Content

Characterization of the mineral content of the settleable, supracoloidal, colloidal, and dissolved solids was accomplished by analyzing the fixed solids of the fractions for 14 commonly occurring anions and cations. Each fraction was markedly different from the rest with respect to the per cent composition of one or more of the elements.

1. Of the mineral weight (fixed solids minus associated oxygen) of the settleable fraction, 50.5 per cent was silicon. Iron, calcium, magnesium, and phosphorus were each present in concentration of 5 to 9 per cent. Outstanding was the small concentration of sulfur, 0.70 per cent.

2. In the supracolloidal fraction, 35.8 per cent of the mineral weight was derived from phosphorus, 15.0 per cent from silicon, and 10.8 per cent from calcium.

3. Calcium and phosphorus constituted 30.9 and 20.5 per cent, respectively, of the colloidal fraction mineral weight.

4. Of the mineral weight of the dissolved solids, 27.4 per cent was sodium, 24.1 per cent was chlorine, 12.0 per cent was sulfur, and 11.4 per cent was magnesium.

Grease

The organic constituents of the supracolloidal and colloidal fractions of the winter composite and the settleable, supracolloidal, and colloidal fractions of the summer composite were separated by solvent extraction into the total grease (soluble in petroleum ether), alcohol-soluble (exclusive of grease), and alcohol-insoluble groups. The total grease was analyzed for saturated and unsaturated free fatty acids, saturated and unsaturated glyceride fatty acids, phospholipids, and unsaponifiable matter. The alcohol-soluble group was analyzed for the amino acid content after hydrolysis. The alcohol-insoluble group was analyzed for pectin, hemicellulose, cellulose, lignin, and the amino acid content after hydrolysis. The summary follows.

1. Glyceride fatty acids comprise the major portion of the total grease of all the fractions.

2. Only a small percentage of the free and glyceride fatty acids were unsaturated, oleic acid being the most important.

3. Phospholipids were found in trace amounts.

4. The unsaponifiable matter represented about 3 to 7 per cent of the total grease in the various fractions.

5. The settleable solids had the smallest proportion of total grease (19 per cent) and the colloidal solids had the greatest (51 per cent).

The differences between the same fraction in the winter and summer composites were more quantitative than qualitative, the summer fractions contributing about twice as much total grease to the raw sewage as the winter fractions.

Amino Acids

Only a small portion of the nitrogenous matter of the sewage fractions from the winter and summer composites was present in the alcohol-soluble group. After acid hydrolysis of the nitrogenous matter of the alcohol-soluble and alcohol-insoluble groups, the amino acids were separated by paper chromatography and quantitatively determined. The 14 amino acids identified were: alanine, aspartic acid, glutamic acid, leucine,

phenylalanine, methionine, valine, glycine, histidine, cystine, serine, threonine, tyrosine, and lysine, listed in the general order of decreasing concentration. From the analysis of the amino acids of the various fractions, the conclusions reached were:

1. There was no apparent pattern of amino acid distribution or regular change in concentration accompanying the change in particle size from one fraction to the next.

2. The same amino acids were generally found in all of the fractions of the winter and summer composites.

3. The per cent of nitrogenous matter in the supracolloidal fraction was about twice as great as that of the settleable or colloidal fractions.

4. The differences between the amino acid contents of the same fraction in the winter and summer composites were more quantitative than qualitative. The amount of nitrogenous matter contributed to the raw sewage by the summer fractions was about twice that contributed by the winter fractions.

Carbohydrates

In the analysis of the alcohol-insoluble matter for carbohydrates, it was found that:

1. Lignin was the constituent of greatest amount in the winter and summer supracolloidal and colloidal fractions.

2. Cellulose was the principle carbohydrate constituent of the summer settleable fraction.

3. Pectins represented less than one per cent of the solids of any of the sewage fractions. They were present in greater amounts in the summer fractions than in the winter fractions, most of the pectin of the raw sewage being contributed by the supracolloidal fraction.

4. The carbohydrates in the summer composite, for which analyses were made, constituted 23.6 per cent of the settleable solids, 11.2 per cent of the supracolloidal solids, and 6.8 per cent of the colloidal.

Acknowledgment

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Industrial Wastes

TIDEWATER'S DELAWARE REFINERY WASTE CONTROL AND TREATMENT*

I. FACILITIES AND TREATMENT METHODS

By A. W. Lewis

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Tidewater's Delaware Refinery is located approximately 15 miles south of Wilmington, Del. The site covers 5,200 acres located on the Delaware River. Refining units and tank fields occupy 10 per cent of the area (Figure 1). They are about 60 to 70 ft above sea level. A belt of marsh borders the river, but subsoil of the farmland on which the principal structures are located is brown, sandy clay supported by heavier clays. Delaware City lies just southeast of the refinery and New Castle is six miles northeast.

Refinery

The refinery consists of a dozen major operating units designed to convert heavy, high-sulfur, crude oil to liquid fuels at the rate of 130,000 bbl/day. The major units are listed below:

Crude unit	Alkylation unit
Fluid coker	Catalytic reformer
Fluid catalytic cracker	Hydrodesulfurizers
Gas plant	Hydrogen plant
Solutizer sweetening units	Udex extraction unit
Polymerization unit	Sulfur plant

To gain capital investment and operating cost advantages, the individual units, for the most part, are the largest of their type. In contrast with a multiplicity of smaller units, the single large units can justify more costly and more reliable components, greater investment in equipment for the handling of wastes, and larger operating expenditures per unit to assure that waste-handling facilities are properly operated.

Waste-Handling Considerations

Air, water, and soil pollution were considered during the design stages of each individual unit as well as for the refinery as a whole. The basic philosophy was to provide facilities for waste handling as close to the source as possible, and to impose as much of the responsibility for effluent control on the individual unit supervisor as was feasible. Adherence to this policy minimizes the generation of wastes. Use of five separate sewer systems avoids difficulties inherent in handling mixtures of contaminants which have been greatly diluted.

Soil Contamination Control

Many old refineries might be thought of as being built upon buried oil lines interspersed with piles and fill. Not infrequently, gathering pits are built from which oil, resulting from leaks and spills, is recovered. To avoid such soil contamination at Delaware, only

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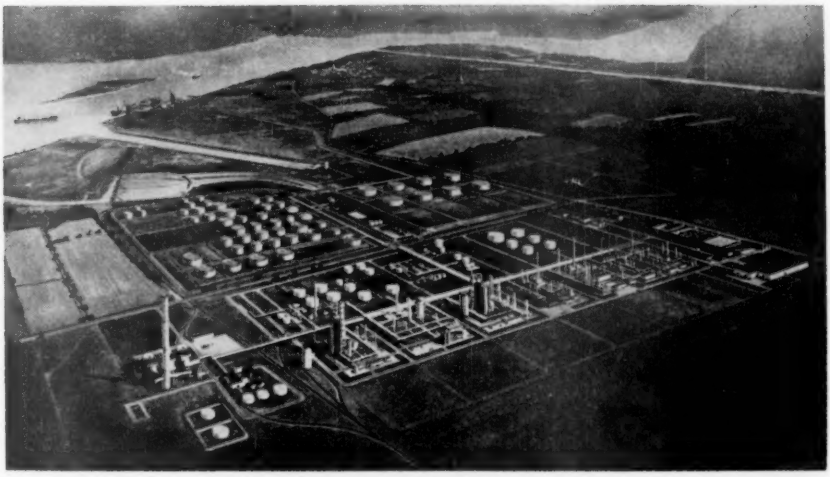

FIGURE 1.—Tidewater's Delaware Refinery.

water mains and electrical conduits are buried. All other lines are carried above ground.

A major source of soil contamination in many refineries results from leaking pump glands. At Delaware, nearly all pumps have mechanical seals which greatly reduce pump-gland leakage. The ground surrounding the operating units is covered with concrete pads. Any spills from pumps or other sources fall on the pad, from which they are directed to the oil recovery system.

Air Pollution Control

Material lost to the atmosphere is confined essentially to stack gases. For example, all safety releases in gas service are vented to a closed blowdown system. Overload on this system is released to smokeless flares. All tanks in volatile hydrocarbon service have floating roofs. Pumps have mechanical seals. Foul-smelling waters are handled in closed systems. Odorous gases removed from foul-water and spent caustic solutions are burned. Catalyst dust from fluid catalytic cracking operations is retained in the unit by three-stage cyclone separators of unusually high efficiency. Approximately 0.005 per cent of the catalyst circulated is lost. Coke fines from the fluid coker are retained with two-stage cyclones. Fluid coke dust not retained by the cyclones is passed with coker flue gas through an auxiliary-fuel fired CO boiler where the escaping coke fines are burned. Thus, the only effluent vented to the atmosphere is stack gas.

The sulfur content of crude oil is between 2 and 3 per cent. Gasoline and distillate fuels, the major products of the refinery, have negligible sulfur because it has been removed by hydrogenation. The resulting hydrogen sulfide is converted to molten sulfur in the sulfur plant. However, sulfur is concentrated in fluid coke and, to a lesser extent, in heavy fuel oil.

The power station, operated by the Delaware Power and Light Company, preferentially burns essentially sulfur-free fuel gas, supplemented by fluid coke. This has, at times, amounted to about 550 tons of fluid coke per day. Heat for the fluid coker is generated by burning coke in the unit. Heat for the fluid catalytic cracker is generated by burning catalyst deposit,

a form of coke, in the unit. The rest of the refinery is fueled with gas generated in refining operations. This gas is scrubbed with diethanolamine for removal of hydrogen sulfide. As a result of burning coke and catalyst deposit, a varying amount of sulfur dioxide exists in gases from a few of the stacks.

After thorough study by air pollution specialists, it was obvious that the best method of sulfur dioxide disposal was by dispersion through stacks made high enough to assure low ground-level concentrations. Although there are 14 major stacks, most of the heaters feeding these stacks are fueled with refinery fuel gas which normally contains hydrogen sulfide in concentrations of less than 20 grains/100 cu ft. Only the power station, sulfur plant, coker, and cracker burn fuels of significant sulfur content. These units have stack heights as follows:

Unit	Stack Height (ft)	Stack Gas Temperatures (°F)	Effective Stack Height (ft)
Power plant	500	290	970
Sulfur plant	225	900	535
Coker	250	550	690
Cracker	230	710	670

Incorporation of these tall stacks has resulted in ground level concentrations of SO_2 well below the acceptable levels which are anticipated from operation of a modern power house utilizing stacks of normal height.

The crude unit is designed so that fluid coke may be used in the future. For this contingency, the crude unit stack has been made 350 ft high with an estimated plume rise of 410 ft at the design exit condition.

Wastewater Control and Treatment

Sewer Systems

The refinery and the Delaware Power and Light Company power station together take about 360 mgd of once-through cooling water from the Delaware River. Storm sewers at the refinery are capable of handling about 370 cfs. Separate sewer systems are provided for cooling and storm water. In addition, there are separate sewers for oily water and for process wastewater. The total wastewater flow from the process area can range up to 620 mgd. The Marine Terminal located about 2 miles from the process area has its own oil recovery facilities.

Cooling Water

Cooling water is taken from the Delaware River by nine 2,000-hp motor-driven vertical centrifugal pumps (Figure 2) and is used in closed tubular heat exchangers. Exchangers in heavy-oil service have been equipped to divert cooling water to the oily-water sewer should a leak develop. Return cooling water is taken through two parallel 84-in. diameter concrete pipes to either two or three parallel separating basins, each measuring 600 by 420 ft and 7.5 ft deep, in which the design maximum flow rate is 4 fpm. At the end of the separating basins are adjustable weirs which permit the removal of up to 10 per cent of the flow. This overflow is directed through flumes to an API gravity separator having five channels, each 70 ft long, 18 ft wide, and 9 ft deep. The skimmed oil, emulsion, and water are returned to the refinery for oil recovery.

Storm Water

Storm water is gathered in a separate sewer system and sent through a single 108-in. diameter pipe to one of three separating basins.

All tanks are enclosed in retaining dikes. Water which collects inside the dikes is removed through 8-in. drains valved on the outside of the dike. A monitor box is located at this point and valved lines lead to the oily-water and the storm sewers. The condition of the water governs the choice of the

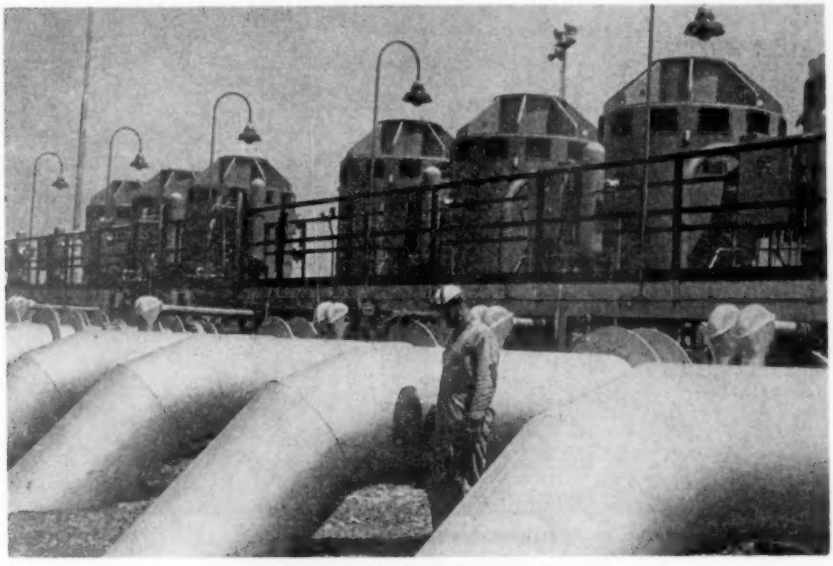

FIGURE 2.—Cooling-water pumping station.

sewer system to be used. This arrangement also permits regulation of the storm-water flow rate.

Other methods for preventing oily water from entering storm sewers were mentioned earlier.

Oily Wastes

Oily water derived from leakage, spills, sample-line flushing, equipment drains, and the like passes through a monitor box or a unit separator at each operating unit. Each is baffled to restrict the flow of oil. The principal objective is to provide unit inspection and to permit oil skimming.

Oily water collected from all units passes to an API gravity separator having four channels each 170 ft long, 20 ft wide, and 8 ft deep. The skimmed oil and emulsion are returned to the refinery and the water joins the storm sewer before it enters the separating basins.

Process Wastewater

Process wastewater is collected from the crude unit, fluid catalytic cracker, fluid coker, and other operations for pretreatment in a foul-water stripper. The flow approximates 800 gpm and contains, primarily, sulfides, oil, ammonia, and some phenols. Stripping with about 20,000 lb/hr of steam maintains an overhead temperature of 190°F. Contaminant removal is over 90 per cent for sulfides, about 60 per cent for ammonia, about 75 per cent for hydrocarbons, and about 30 per cent for phenols and acid oils. The overhead from the tower is incinerated. Two-thirds of the stripped wastewater is returned for reuse at the fluid catalytic cracker and as desalter water where the phenol and oil content is reduced by solution in crude oil.

Spent caustic used in treating straight-run stocks, water from crude oil electrical desalting, and water used for washing products after caustic treating is processed in a flue-gas stripper. Flue gas enters the tower at about 400°F. Carbon dioxide in the flue gas springs hydrogen sulfide and other weakly acidic materials

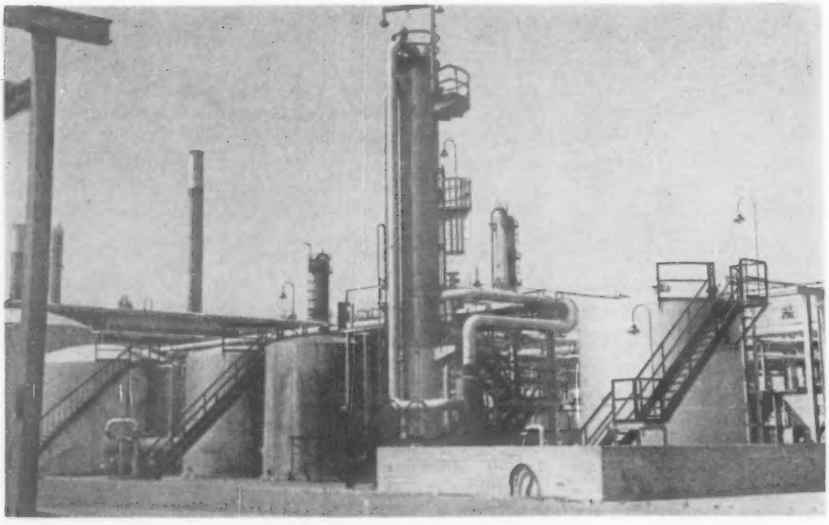

FIGURE 3.—Flue-gas contactor.

which are taken overhead and burned. The stripped water contains as much as 1.5 tons/hr of salts, primarily sodium chloride and sodium carbonate. Objectionable impurities are greatly reduced by this operation.

Spent caustic from treating cracked stocks, unlike caustic from treating straight-run stocks, contains in addition to sulfides and mercaptides, phenols and so-called "acid oils." Such caustics are stripped with flue gas in a 400-bbl batch still. Figure 3 is a picture of the facility and Figure 4 is a diagrammatic flow chart. By keeping this caustic out of the other waste-flow streams, the phenols remain concentrated, facilitating recovery. In this operation, the caustic is blown until a pH of about 9.5 is obtained. It is then allowed to separate into two liquid layers. The top layer of "acid

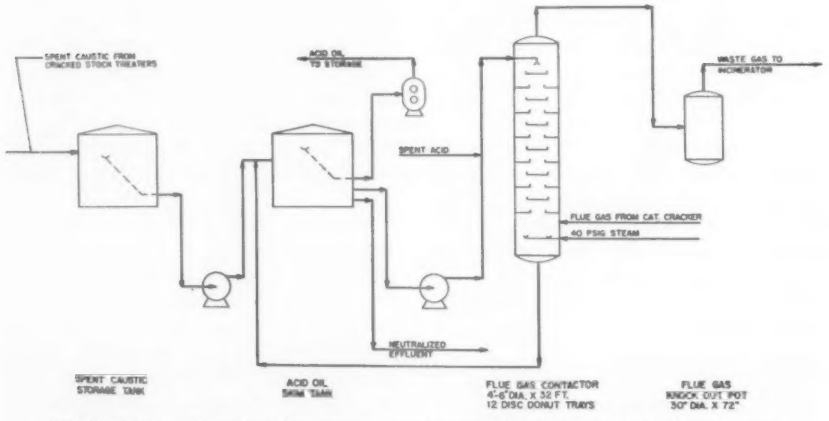
SPENT CAUSTIC FROM CRACKED STOCK TREATERS
ACID OIL TO STORAGE
WASTE GAS TO INCINERATOR
SPENT ACID
FLUE GAS FROM CAT. CRACKER
40 PSIG STEAM
NEUTRALIZED EFFLUENT
SPENT CAUSTIC STORAGE TANK
ACID OIL SKIM TANK
FLUE GAS CONTACTOR 4'-6" DIA. X 32 FT. 12 DISC DONUT TRAYS
FLUE GAS KNOCK OUT POT 30" DIA. X 72"

FIGURE 4.—Flowsheet for spent caustic neutralization and acid oil recovery.

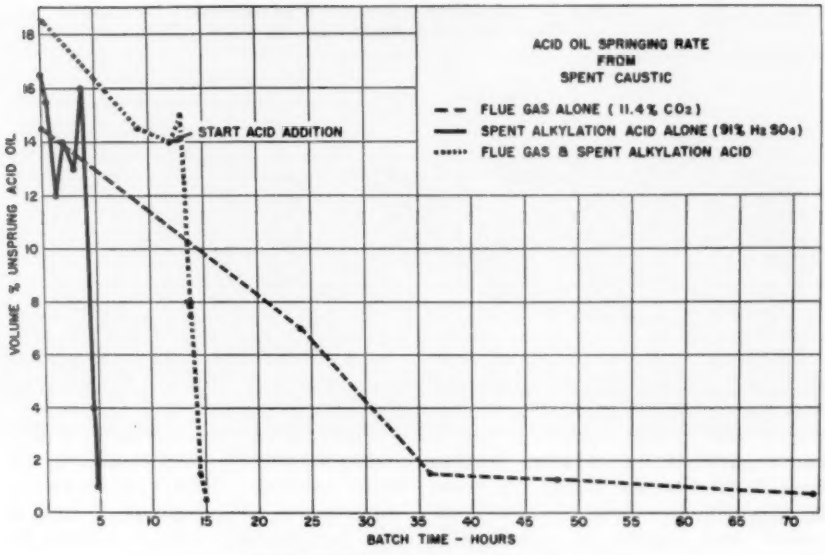
ACID OIL SPRINGING RATE
FROM
SPENT CAUSTIC
FLUE GAS ALONE (11.4 % CO2)
SPENT ALKYLATION ACID ALONE (91% H2 SO4)
FLUE GAS & SPENT ALKYLATION ACID
START ACID ADDITION
VOLUME % UNSPRING ACID OIL
BATCH TIME - HOURS

FIGURE 5.—Acid-oil springing rate.

oil'' is skimmed and sold. The lower layer is a concentrated solution of sodium carbonate formed in the reaction. Crystallization of salts in the tower must be avoided, but a maximum salt concentration in the water layer is desirable to salt out phenols. This balance is achieved by careful adjustment of the caustic content of the stripper feed by water dilution.

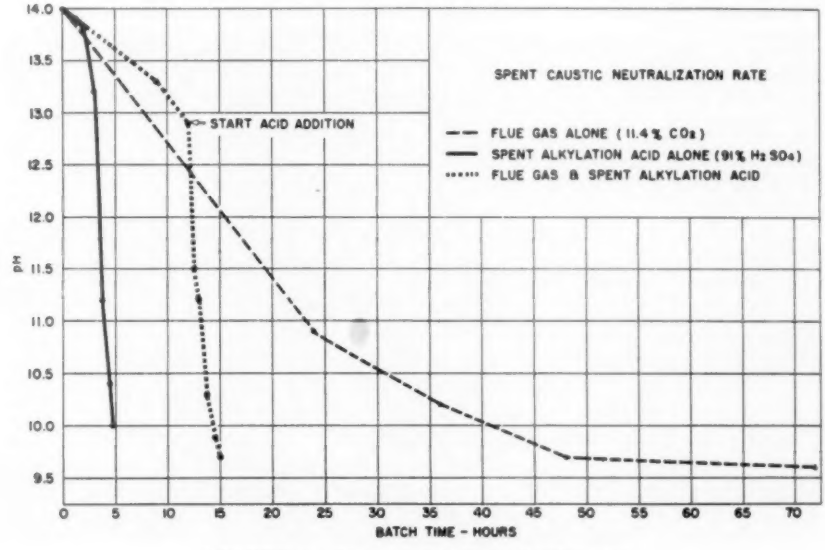
SPENT CAUSTIC NEUTRALIZATION RATE
FLUE GAS ALONE (11.4 % CO2)
SPENT ALKYLATION ACID ALONE (91% H2 SO4)
FLUE GAS & SPENT ALKYLATION ACID
START ACID ADDITION
pH
BATCH TIME - HOURS

FIGURE 6.—Spent caustic neutralization rate.

TABLE I.—Comparison of Removal Efficiencies of Three Different Springing Methods

Constituent	Typical Charge (lb)	Typical Effluent (lb)	Removal Efficiency (%)		
			Flue Gas Alone	Flue Gas and Acid	Acid Alone
Acid oil	20,000	700	95.3	97.6	94.6
Sulfide, as S	50	3	90.7	94.3	96.2
Mercaptide, as S	1,500	10	97.5	99.8	99.7
Alkalinity, as NaOH	14,500	2,500	53.8	83.6	89.6
pH	14.0*	9.7*	—	—	—

* pH units.

In operation, about 400 bbl of caustic is pumped into the skim tank and then continuously pumped over the top of the column while flue gas is blown through the column. It has been found that the design gas velocity through the column of 3 fps is excessive and results in considerable carry-over. In practice, it is necessary to operate at 1.5 fps. Operation at the lower gas velocity has halved the column's processing capacity. It has not, of course, decreased the percentage of contaminants removed. To decrease operating time, the use of spent alkylation acid as a supplement to, and as a replacement for, flue gas has been examined.

Figure 5 compares the time for processing a batch of spent caustic by the three methods. Figure 6 shows the comparative pH changes. A pH of 9.7 is sufficiently low to release the acid oil. Using spent alkylation acid rather than flue gas decreases neutralization time from three days to five hours.

The comparative contaminant-removal efficiencies of the three springing methods are shown in Table I. In

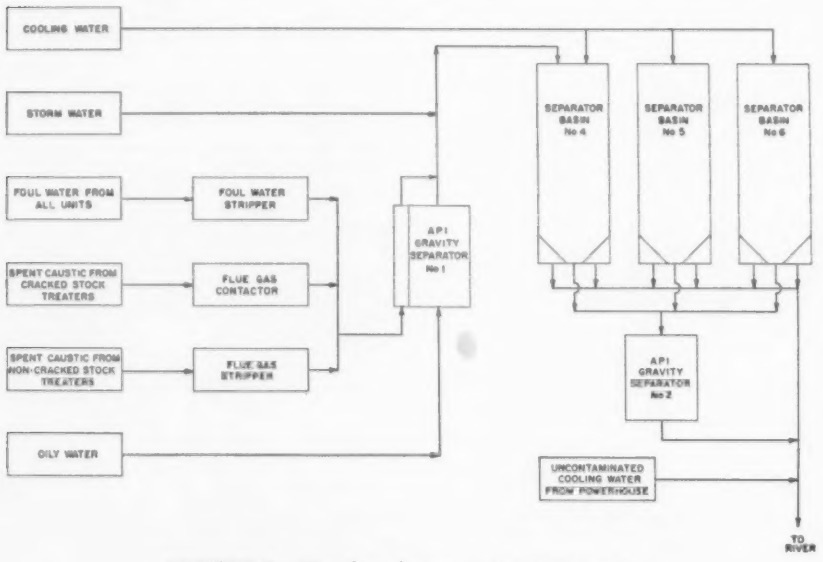

FIGURE 7.—Flowsheet for waste treatment system.

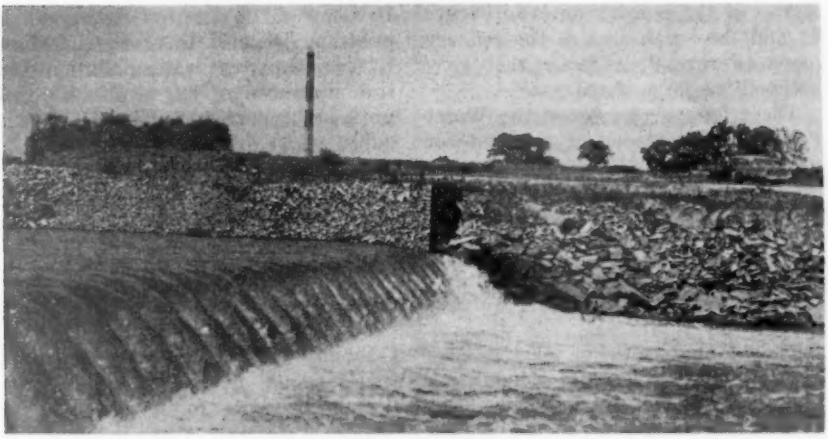

FIGURE 8.—Riprap at refinery outfall.

the cases studied so far, there has been sufficient heat of reaction from use of spent alkylation acid to make auxiliary heat unnecessary.

Waste process-water from all flue-gas strippers is sent to API Separator No. 1 where it enters a separate channel for skimming (Figure 7). The skimmed process water joins the skimmed oily water and both are discharged to the storm sewer ahead of the large separating basins.

Sanitary waste is handled in septic tanks located as required throughout the refinery. Overflow from the septic tanks is discharged to the storm sewers.

Effectiveness of Abatement Measures

The refinery has been in operation for over two years. Inspections of the

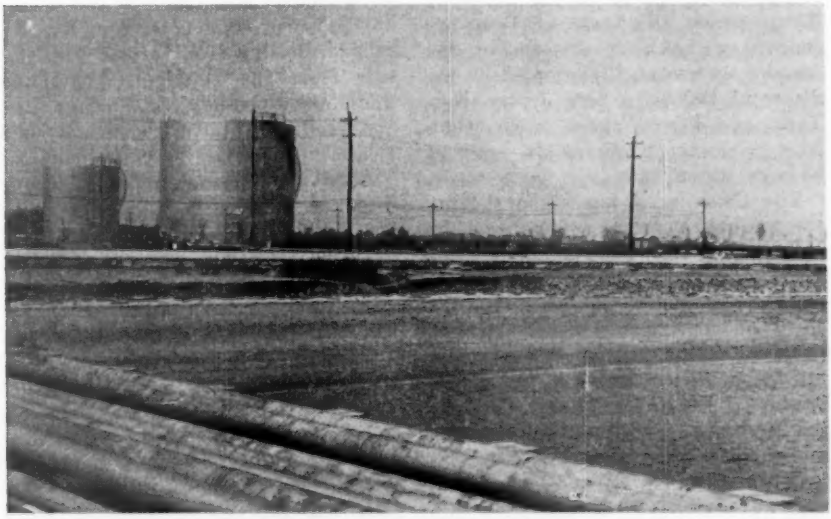

FIGURE 9.—Beach at refinery piers.

riprap at the refinery outfall (Figure 8) and the beach area at the refinery piers (Figure 9) indicate that very little oil has been discharged.

The refinery has assisted the Water Pollution Commission of the State of Delaware in a month-long sampling program designed to assess the effectiveness of present water pollution control measures. The results of this work are reported in Part II of this paper.

II. EVALUATION OF TREATMENT METHODS

By A. Joel Kaplovsky

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The adopted policy of the Delaware Water Pollution Control Commission (1) requires that all problems connected with water pollution be investigated and studied. Detailed reports of the findings, including recommendations, must be made. In addition, the Commission has the power to conduct scientific experiments, investigations, and research to discover economical and practicable methods for the elimination, disposal, or treatment of sewage, industrial wastes, and other wastes.

Delaware does not have standards of water quality, nor does it have minimum requirements. An exception to the latter applies to the Delaware River, where the State of Delaware concurs with the provisions of the Incodel agreement (2) adopted by the States of Delaware, New Jersey, New York, and Pennsylvania which stipulates minimum requirements for that body of water.

The Commission has taken the position that greater equity can be achieved if each problem or area is given specific evaluation. A waste discharge is studied on its merits. The effect of an existing discharge or a proposed discharge is studied to evaluate its influence on the best water usages. Basin investigations show existing stream conditions, waste loads, and the best water usages. These findings are submitted to the offender with recommendations for treatment.

The request of the Tidewater Oil Company for refinery-waste treatment requirements instigated several important decisions to be made by the Water Pollution Commission. The proposed refinery site would discharge wastes to the lower Delaware estuary, heretofore studied only sporadically and in not too much detail with respect to sanitary quality. Extensive recreation and shellfish interests commence approximately 15 miles downstream. In addition, self-purification capacity within an estuary is complex, and proposed methods for this determination leave much to be desired.

Formal request from the Tidewater Oil Company regarding State quality requirements was made in the spring of 1955. At this time, complete details of loadings of various constituents from the anticipated operation were made available. Various new and modified pretreatment and final treatment facilities were proposed.

Based on a Delaware River survey made in 1952 (3), and a thorough search of the literature pertaining to potential toxic and oxygen-demanding constituents present in oil refinery wastes, the degree of treatment needed had to be ascertained by the State.

During plant construction in 1956, an extensive sanitary quality study (4) was made of the lower Delaware River estuary to establish a base line of water quality. The sanitary quality of the entire estuary from the Delaware Bay to Trenton, N. J., a distance of 90 miles, has been studied

(5) extensively during the summers of 1957 and 1958. General observations, with respect to these studies, are included in this paper.

Full plant operation commenced in the summer of 1957. Since the initial request to construct a refinery in Delaware, the cooperation and compliance with the requests of the Water Pollution Commission by the Tidewater Company have been exemplary.

Methods of Evaluation

The method of approach used for evaluating the efficiency of the waste-handling operations and the effect of this discharge upon state waters was divided into four basic steps, namely:

1. The potential pollutional load was evaluated prior to construction by estimating:

   (a) the waste concentrations in the effluent from the proposed steam and flue-gas strippers;
   (b) the waste concentrations if either of the proposed strippers broke down;
   (c) the maximum constituent concentrations within the river in the vicinity of the waste outfall under various conditions of stripper breakdown; and
   (d) a comparison of concentrations developed in (c) with generally accepted quality standards for river water receiving multiple use.

2. Efficiency of the waste-handling operation was determined by:

   (a) compositing hourly waste samples during a full shift for four consecutive weeks;
   (b) analyzing the composite samples in accordance with "Standard Methods" (6) for pH, BOD, temperature, ammonia-nitrogen, phenolic compounds, sulfide, cyanide, turbidity, COD, and oil (oil analyses were performed by refinery personnel); and
   (c) comparing estimated reductions by the treatment facilities with actual reductions after one year of plant operation.

3. Ring studies of the sanitary quality of the river water were made to determine if a localized problem existed. All stream sampling was carried out during slack-water conditions upstream and downstream from the point of discharge.

4. The effect of this discharge on the over-all estuary water quality was evaluated by applying the modified "same-slack" technique (4)(7). Various conditions inherent to estuarine waters were taken into consideration in this evaluation.

Evaluation of Proposed Waste-Handling Procedures

Effluent Concentrations

It has been pointed out in Part I of this paper that the major portion of the work load with respect to reducing chemical (but not oily) waste products is accomplished by three stripper operations. The foul-water stripper (Stripper A) is provided for steam stripping of the segregated waste. The charge to this stripper contains a major portion of the sulfides, essentially all the ammonia, some phenolic compounds, and a major portion of the hydrocarbons and aliphatic acids.

The flue-gas neutralizing stripper (Stripper B) provides for stripping and neutralizing crude desalter water and spent caustic from the processing of straight-run stocks. This stripper is charged with comparatively small quantities of hydrocarbons and nitrogen-base compounds. However, it does handle a sizable portion of the plant's sulfide constituents.

The third stripper (Stripper C) is also a flue-gas neutralizing unit provided to neutralize spent caustic used

TABLE II.—Estimated Effluent Waste Concentration at Full-Stream Operation under Various Conditions

Condition	Sulfides (mg/l)	Ammonia (mg/l)	Cyanides (mg/l)	Phenolic Compounds (mg/l)	Hydrocarbons (mg/l)	Aliphatic Acids (mg/l)	Amines (mg/l)	Nitrogen-Base Compounds (mg/l)
1[a]	0.540	0.204	0.23	0.196	0.70[b]	—	—	—
2[c]	6.040	1.080	0.062	0.830	2.90	0.65	0.031	—
3[d]	6.85	0.204	0.0235	0.196	1.32	0.157	—	0.196
4[e]	0.67	0.204	0.0235	5.1	0.93	0.157	—	0.39

[a] Foul-water stripper (Stripper A) plus flue-gas neutralizing stripper (Stripper B) plus flue-gas neutralizing stripper for spent caustic from catalytically cracked stock (Stripper C).
[b] Includes aliphatic acids.
[c] Stripper B plus Stripper C.
[d] Stripper A plus Stripper C.
[e] Stripper A plus Stripper B.

in treatment of catalytically cracked stocks containing phenols and thiophenolates. This unit handles the major portion of the phenolic compounds. The other constituents contained in the charge to this stripper are minor compared with the constituent charges directed to the other units.

Prior to construction, the waste effluent concentrations at full operation were estimated. These estimates are shown in Table II. The concentrations shown represent the levels after mixing with the plant's cooling water.

When all three strippers are in operation (Condition 1), the waste concentrations in the effluent are low. It is possible, however, that mechanical breakdown or excessive corrosion would cause one or more of the strippers to be taken out of service. Hence Table II also shows estimates of waste concentrations that obtain for different combinations of strippers. If Stripper A (Condition 2) or Stripper B (Condition 3) is out of service, a rather high sulfide content in the effluent would result. The Water Pollution Commission, therefore, stipulated that sufficient storage be avail-

TABLE III.—Estimated Waste Concentrations at Outfall[a] and Maximum Permissible Limits

Condition	Sulfides[b] (mg/l)	Ammonia[c] (mg/l)	Cyanides[d] (mg/l)	Phenolic Compounds (mg/l)	Hydrocarbons[e] (mg/l)	Total Oil (mg/l)
1[f]	0.27	0.102	0.012	0.088	0.35	<5.0
2[f]	3.02	0.504	0.031	0.415	1.45	<5.0
3[f]	3.43	0.102	0.012	0.088	0.66	<5.0
4[f]	0.34	0.102	0.102	2.55	0.47	<5.0
Max permissible river conc.	1 to 2[g]	2.5 to 10[g,h]	0.20[g]	0.08 to 0.7[g,i]	3.0	7.0[g,j]

[a] Refers to turning-basin area which extends 2,000 ft from shore; twofold dilution.
[b] Fish avoid sulfides if possible.
[c] Buffer capacity and pH are important considerations.
[d] Rapidly reduced by bacteria.
[e] Hydrocarbons contribute BOD.
[f] Refer to Table II for stripper conditions.
[g] Value from Ref. 9.
[h] Value from Ref. 10.
[i] Generally 1 mg/l or less satisfactory for most fish; 5 mg/l lethal.
[j] 50 gal of oil/sq mile visible.

able to retain the charge to any stripper which may become temporarily inoperative.

River Concentrations

Initially, the volume of water available for dilution had to be known. An extremely conservative basis was adopted, in that the volume in the adjacent ship-turning basin was considered as the total available. Further, it was assumed that, because of the temperature and organic compounds in the effluent, the discharge would concentrate in the upper 5 ft of the river (8), thereby imposing additional limitations on available dilution. Consequently, it was estimated that under critical conditions a twofold dilution would not be exceeded. Estimates of waste concentrations under these initial mixing and dilution conditions are shown in Table III. The maximum concentrations considered acceptable are also shown. Ineffective stripper operation (Conditions 2 and 3 in Table II) could conceivably present a problem. However, in an estuary the size of Delaware, only a localized problem would result.

The estimated concentrations in the river are valid only if similar constituents from upstream sources are not present. With respect to the influence of upstream sources of pollution, existing information showed that the proposed Tidewater site was located beside a comparatively unpolluted body of water.

Insufficient information existed in 1955 as to the tidal area's waste-build-up rate and self-purification capacity, two important counteracting forces peculiar to estuarine waters. It was deemed appropriate, therefore, that the dilution approach referred to above be used until additional information became available.

Operating Results

After a year's operation the effectiveness of the treatment facilities was measured and compared with the estimated effectiveness. This comparison is summarized in Table IV. During the month-long period of concentrated sampling and evaluation, the estimated removal efficiencies, with one exception, were closely approached. Ammonia removal was 26 to 33 per cent less than estimated. However, the ammonia concentration in the stream was still within acceptable limits.

In Table V the average quality of the effluent during July 1958 is com-

TABLE IV.—Estimated and Actual Treatment Efficiencies and River Loadings

Waste Constituent	Estimated			Actual							
				7/1/58		7/8/58		7/15/58		7/29/58	
	Total Waste* (lb/day)	Waste to River (lb/day)	Removal (%)	Waste to River (lb/day)	Removal (%)	Waste to River (lb/day)	Removal (%)	Waste to River (lb/day)	Removal (%)	Waste to River (lb/day)	Removal (%)
Sulfides	29,600	288	99	2,050	93	0	100	615	98	294	99
Ammonia	5,160	672	87	2,025	61	—	—	2,100	60	2,360	54
Cyanides	288	48	82	—	—	—	—	0	100	0	100
Phenolic compounds	19,380	672	96	710	96	627	97	636	97	1,020	95
Sodium hydroxide	11,650	—	100	—	—	—	—	—	—	—	—
Mercaptides	10,350	—	100	—	—	—	—	—	—	—	—
Sodium sulfide	9,720	—	100	—	—	—	—	—	—	—	—
Potassium hydroxide	359	—	100	—	—	—	—	—	—	—	—
Hydrocarbons	19,820	1,750	91	—†	—	—	—	—	—	—	—
Nitrogen-base cmpds.	1,800	—	100	—	—	—	—	—	—	—	—
BOD, total‡	188,000	8,000	87	8,380	96	31,600	78	9,520	95	19,310	90
COD, total		17,000	—	—	—	—	—	—	—	—	—

* Refinery production estimated @130,000 bbl/day.
† BOD and COD attributed to hydrocarbons included in total BOD and COD.
‡ Estimated. Includes total-load—5-day BOD.

TABLE V.—Effluent Quality Compared with Delaware River Water during July 1958

Sampling Point	Sulfides (mg/l)	Ammonia (mg/l)	Cyanides (mg/l)	Phenolic Compounds (mg/l)	Hydrocarbons (mg/l)	Total Oil (mg/l)
Refinery effl.	0.40	1.10	0.0	0.26	7.61	0.25
Cooling-water infl.	0.12	0.373	0.0	0.0	1.80	<0.2
Del. River, main channel*	0.51	0.27	0.0	0.0	3.15	<0.2
Max permissible river conc.	1 to 2	2.5 to 10	0.20	0.08 to 0.7	3.0	7.0

* Upstream beyond zone of influence.

pared with the average quality of cooling water and water from the main river channel. River concentrations were always less than permissible maxima.

Vicinity Investigations

The cooling water intake for the Tidewater Refinery withdraws river water at a depth of 40 ft. The treated waste is discharged at the surface, approximately 0.68 mile upstream. Midway between the shores of Delaware and New Jersey, and directly opposite the cooling-water intake and waste outfall, is Pea Patch Island (Figure 10). This island has a jetty which extends northward a distance of 3.5 miles, jointly creating a barrier approximately 5 miles long. The main ship channel is to the east of Pea Patch Island, whereas the secondary or the Tidewater channel is located west of Pea Patch Island and its jetty. This configuration within the Delaware River could have the tendency of confining or concentrating the refinery discharge between this barrier and the Delaware mainland. Consequently, it was considered important that this confined area be given additional study.

To evaluate the zone of influence, it was necessary to determine the sanitary quality during periods of high-water and low-water slack within the confined area. Several series of ring-type studies were made and the results of a typical series are shown in Table VI. The results show that no localized problem exists. In fact, it is and has been difficult to establish any evidence of refinery waste much beyond the Delaware shoreline.

Several minor variations deserve comment. Temperature variations, over a distance of approximately 6

TABLE VI.—Zone of Influence Studies of River Quality during Slack Water

Sampling Station*	Temp. (°C)		pH		BOD (mg/l)	NH_3-N (mg/l)		NO_2-N (mg/l)		NO_3-N (mg/l)	Phenol (mg/l)	
	7/15 HWS†	7/17 LWS‡	7/15 HWS†	7/17 LWS‡	7/17 LWS‡	7/15 HWS†	7/17 LWS‡	7/15 HWS†	7/17 LWS‡	7/17 LWS‡	7/15 HWS†	7/17 LWS‡
1	27.8	—	6.9	—	—	0.18	—	0.022	—	—	.018	—
2	27.8	—	6.7	—	—	0.22	—	0.022	—	—	.013	—
3	28.0	—	6.8	—	—	0.31	—	0.034	—	—	0	—
4	27.6	27.0	6.9	7.1	2.3	0.23	0.25	0.023	0.053	1.5	0	0
5	27.8	27.0	6.9	7.1	1.2	0.15	0.175	0.016	0.046	1.43	0	0
6	27.8	27.0	7.0	7.2	1.7	0.23	0.25	0.020	0.037	1.58	0	0
7	27.8	26.8	7.0	7.1	1.9	0.20	0.200	0.015	0.030	1.28	0	0
8	—	—	—	7.2	0.3	—	0.175	—	0.031	1.55	0	0
9	27.4	27.0	7.0	7.0	4.7	0.20	0.20	0.022	0.055	1.70	0	0

* Sampling stations are shown in Figure 10.
† HWS is high-water slack, July 15, 1958.
‡ LWS is low-water slack, July 17, 1958.

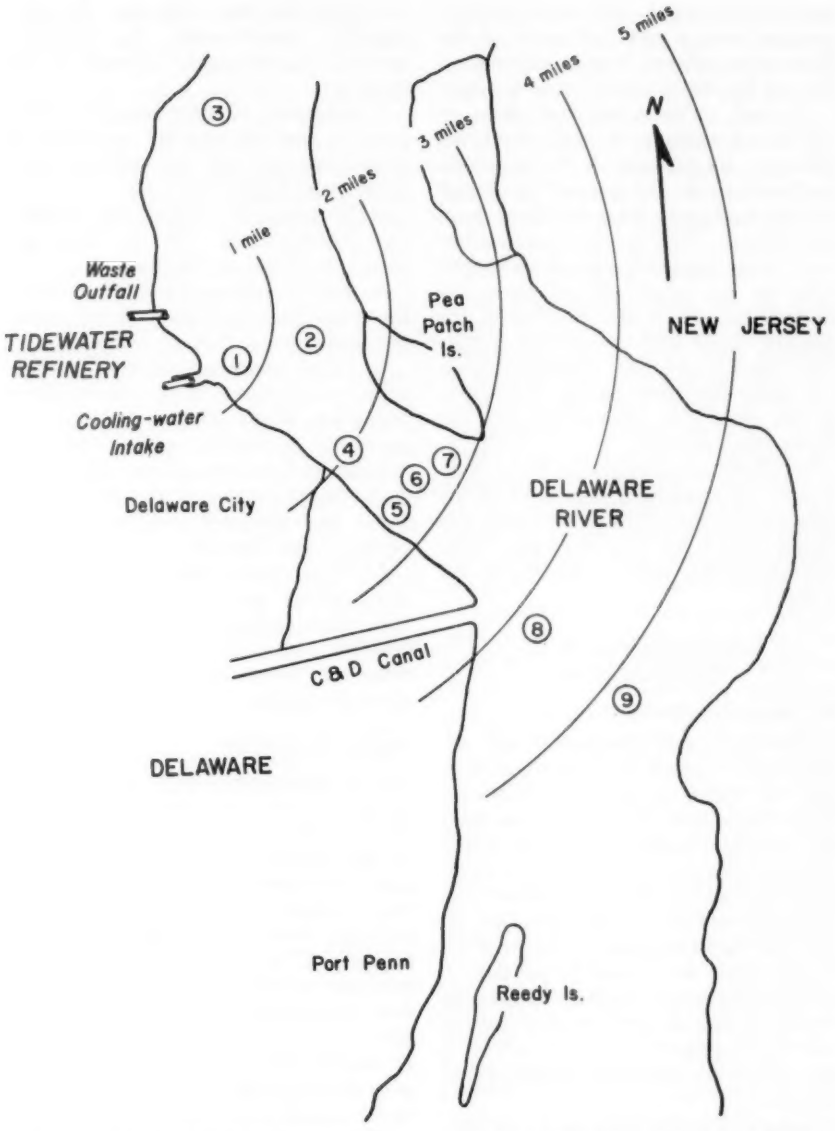

FIGURE 10.—Location of sampling stations in the vicinity of the Tidewater Refinery.

miles, were so small that it is concluded that the Tidewater effluent has no effect on the river temperature. In fact, it appears to have no effect on the cooling water intake 0.68 mile downstream. The temperature observations confirm the findings of model studies (11).

All BOD values for samples collected during low-water slack are quite low except for samples taken at the extreme downstream position in the

main ship channel. This latter concentration level is not indicative of the Tidewater effluent but is representative of the estuary quality as a whole.

Various nitrogen analyses show no significant changes in and about the effluent. An increase in the ammonia- and nitrite-nitrogen content was found during high-water slack upstream from the effluent. The increased concentration levels observed cannot be attributed to the plant effluent since the normal nitrogen concentrations in the estuary itself are within this range. The nitrate-nitrogen content during low-water slack periods also was higher in the main ship channel than in the Tidewater channel.

Evidence of phenol was found only within the immediate proximity of the effluent outfall. No other phenol was found within the area of study. Cyanide analyses were negative at all times.

Self-Purification of the Delaware River

Problems Involved

The rapid economic growth and development experienced in Delaware and in states within the Delaware River Basin have accentuated the need for extensive pollution studies of the Delaware estuary. The state of Delaware has expended considerable time and effort to evaluate the pollution in, and the self-purification capacity of, this body of water and to predict, if possible, its future sanitary quality as it may be affected by increased growth and development and/or controlled flow of the river through upstream impoundments.

Some of the problems to be encountered in evaluating self-purification capacity and sanitary quality in an estuary may be summarized as follows:

1. Estuaries have different mixing characteristics from those of a straight-run river.

2. Theories and formulas for biochemical stabilization in non-tidal streams do not apply directly to an estuary.

3. Selection of representative samples for analysis and the collection of these samples can be difficult and time-consuming (12).

4. Theories of tidal-prism mixing and flushing time (13)(14) have not found universal application.

5. Factors influencing mixing, flushing time, and biochemical stabilization are numerous within an estuary.

6. River models employed for estuarine research use inert substances as indicators in an attempt to duplicate prototype conditions with respect to mixing and transit time. However, such findings are not directly applicable to substances subject to biochemical stabilization.

7. The need for information on self-purification capacity under steady state flow conditions, as induced by low-flow augmentation, has or will become of paramount importance in many estuaries.

Status of Studies

A comprehensive study of the water resources of the Delaware River Basin is being conducted by the Corps of Engineers. The need for a complete inventory of the Delaware's sanitary quality and a practical understanding of its self-purification capacity is both vital and immediate. In view of the time limitations and the characteristics of the Delaware River, an all-out effort is being made to hasten this evaluation by applying procedures which can provide a good approximation of existing conditions.

The estuarine portion of the Delaware River from the Bay to Trenton, N. J., covers a distance of approximately 90 miles. This river is essentially a straight-run river and compared with other estuaries is considered quite shallow. The deeper waters of the river are rather sharply

defined with the maximum depth deviating very little from the dredged, 40-ft channel. In addition, an excellent river model exists at the Corps of Engineers' Waterways Experiment Station at Vicksburg, Miss. Many studies (15)(16) with respect to flushing time, chloride, and sediment movements have been conducted on this model.

The initial problem in the study of pollution was to establish a procedure whereby the river quality could be determined in the shortest possible time and the many variables inherent to an estuary kept at a minimum. In 1956 a modified "same-slack" procedure (4)(7) was developed. At first, this procedure was used for the lower reach of the estuary, but during the fall of 1956, it was applied to the entire estuary in cooperation with Incodel, the states of New Jersey and Pennsylvania, and the city of Philadelphia. These investigations were continued during the summers of 1957 and 1958.

Sampling during studies on the Delaware River model at Vicksburg is normally performed at high- and low-water slack, and consequently a correlation does exist between the prototype studies and those of the model. Within the past two years studies on continuous waste discharges have been performed on the river model by the duPont Company (17) and the New Jersey Zinc Company (18). Specific dispersion characteristics were evident from these studies. The state of Delaware is contemplating further work at Vicksburg for the purpose of determining the buildup rates of continuous waste discharges from various locations in the estuary with the objective of estimating assimilative capacity. Present tentative interpretation of the experimental work performed by the duPont Company and the New Jersey Zinc Company point up the interesting fact that the total daily discharge to this estuary may represent less than 10 per cent of the total pollution load within the estuary, purely on the basis of dispersion, after a state of equilibrium has been reached. This observation, if valid, further confirms the present contention that the "lion's share" of pollution existing in the river is in waters 20-ft deep or deeper.

Effect of Refinery Discharge

To evaluate the effect of the Tidewater Refinery discharge within the Delaware estuary, river data collected after one year of operation were correlated with data collected during "same-slack" periods for the years 1956, 1957, and 1958. Although this "same-slack" procedure provides a means of determining sanitary quality in the entire estuary at equilibrium on a single day, comparisons with data similarly collected can be made only if specific variables are taken into account. For example, since temperature has such a controlling influence on the rate of stabilization, only those series having similar temperatures can be compared directly. Further, flow conditions existing prior to the period of the sampling will influence the findings at a given location. Increased flows lessen the time of transit from an upstream source of pollution to a downstream location. This is reflected in the analyses, for less stabilization takes place in the shorter transit period. Moreover, from an evaluation of the many series of prototype studies made, it is evident that the chloride content in the lower estuary is far more representative of past flow records than either the daily flow or the 10-day average flow prior to the period of sampling.

The sanitary quality in the lower Delaware River between 1956 and 1958 during low-water slack is shown in Tables VII and VIII. Each table groups results of similar temperatures. Table VII presents groupings in which the average temperatures are

TABLE VII.—Sanitary Quality in Lower Delaware River between 1956 and 1958 during Low-Water Slack

Date	Sampling Location[a] (miles from Del. Bay)	pH	DO Sat. (%)	BOD (mg/l)	NH_3-N (mg/l)	NO_2-N (mg/l)	NO_3-N (mg/l)	Turb. (mg/l)	Chlorides (mg/l)	Temp. (°C)
8/20/57[b]	9.28	6.70	73	1.5	0.625	0.108	1.2	30	4,950	23.2
	15.38	6.90	64	1.1	0.800	0.132	1.1	45	3,400	23.2
	21.18	6.75	53	1.9	1.01	0.193	1.1	39	2,525	23.6
	26.00	6.37	39	2.65	1.32	0.291	1.17	36	1,883	24.1
8/9/56[c]	9.28	6.77	47.7	—	0.142	0.049	—	62	1,457	24.0
	15.38	6.67	37.1	1.7	0.158	0.050	—	125	728	25.17
	21.18	6.67	25.1	1.1[d]	0.142	0.064	—	81	275	24.3
	26.00	6.67	trace	1.0[d]	0.242	0.081	—	73	80	24.7
9/3/58[e]	9.28	7.1	69.6	2.1	0.315	0.121	1.0	40	1,340	23.8
	15.38	7.2	57.7	1.3	0.275	0.049	0.875	45	645	23.8
	21.18	7.2	50.2	2.8	0.220	0.077	0.937	51	269	24.2
	26.00	7.0	26.3	4.3	0.200	0.110	0.900	48	103	24.3
7/1/58[f]	9.28	7.4	57	3.85	0.365	0.026	—	53	840	24.2
	15.38	7.4	34	3.40	0.270	0.065	—	68	400	24.2
	21.18	7.3	19.5	7.65	0.477	0.130	—	67	129	24.0
	26.00	7.3	16.0	8.50	0.610	0.136	—	74	42	24.2

[a] Tidewater effluent enters Delaware River secondary channel at Mile 16; secondary channel meets main channel at Mile 13.55.
[b] 10-day avg flow at Trenton, N. J., prior to date was 1,733 cfs.
[c] 10-day avg flow at Trenton, N. J., prior to date was 5,259 cfs.
[d] Toxicity indicated.
[e] 10-day avg flow at Trenton, N. J., prior to date was 4,958 cfs.
[f] 10-day avg flow at Trenton, N. J., prior to date was 3,681 cfs.

TABLE VIII.—Sanitary Quality in Lower Delaware River between 1956 and 1958 during Low-Water Slack

Date	Sampling Location* (miles from Del. Bay)	pH	DO Sat. (%)	BOD (mg/l)	NH_3-N (mg/l)	NO_2-N (mg/l)	NO_3-N (mg/l)	Turb. (mg/l)	Chlorides (mg/l)	Temp. (°C)
8/15/57†	9.28	7.50	82.0	3.90	0.22	0.096	1.78	40	4,800	25.1
	15.38	7.40	68.0	1.40	0.33	0.100	1.55	40	3,250	25.3
	21.18	6.90	60.0	1.90	0.49	0.135	1.55	33	2,450	25.4
	26.00	6.43	43.0	3.15	0.60	0.277	1.67	35	1,492	25.8
8/23/56‡	9.28	7.17	83.3	1.60	—	—	—	35	2,340	25.0
	15.38	6.80	68.4	1.20	0.125	0.051	2.2	57	1,270	25.5
	21.18	6.33	48.3	2.50	0.200	0.066	1.8	55	603	25.5
	26.00	5.80	38.7	—	0.267	0.124	1.5	43	177	26.0
8/19/58§	9.28	7.80	61.0	0.7	—	0.03	1.20	58	1,460	25.0
	15.38	7.80	52.9	2.7	—	0.016	—	68	700	25.6
	21.18	7.70	37.1	5.1	—	0.028	1.26	93	293	25.8
	26.00	6.87	24.3	2.2	0.08	0.061	1.09	62	80	25.8

* Tidewater effluent enters Delaware River secondary channel at Mile 16.0; secondary channel meets main channel at Mile 13.55.
† 10-day avg flow at Trenton, N. J., prior to date was 2,049 cfs.
‡ 10-day avg flow at Trenton, N. J., prior to date was 4,027 cfs.
§ 10-day avg flow at Trenton, N. J., prior to date was 3,681 cfs.

approximately 1°C less than those shown in Table VIII. Further, data for a particular day are arranged in descending order with respect to chloride content. The lower chloride concentrations indicate higher stream flows prior to the period of sampling. Two general observations may be made from these tabulations:

1. As river flows increase, water quality is impaired. This was referred to previously when the effects of transit time were noted. This effect was also evident in the upper reaches of the estuary.

2. In all cases, stabilization and recovery of upstream sources of pollution are clearly evident in each of the years studied, and the differences in concentration levels in 1956 as compared with 1958 are not significant. The general sanitary quality of the river in 1956 and 1957 does not differ from the findings in 1958. It has, therefore, been concluded that present waste-handling facilities at Tidewater's Delaware Refinery is not only satisfactory but after one year of full operation the general sanitary quality of the estuary within the zone of influence of this plant has not changed.

Summary

A brief description is presented of Tidewater's Delaware Refinery, the largest new refinery ever built as a single project. State-industry coordination is briefly summarized. Detail is given with respect to types of wastes derived from each operation, pretreatment of wastes, and final treatment facilities. The estimated waste loads and anticipated reductions through treatment are compared with operating data.

The anticipated effect of treated waste on the quality of the receiving water is discussed. Results of ring studies to determine local effects are included. The effect on over-all estuarine water quality is discussed. Present waste-handling methods were found to be satisfactory.

Conclusions

1. A study of the efficiency of waste prevention measures at Tidewater's Delaware Refinery showed that:

(a) Original estimates of waste reductions by steam and flue-gas stripping are in good agreement with operational findings.
(b) The removal of ammonia compounds, however, was approximately 25 per cent less than estimated.

2. Studies of the Delaware River during high- and low-water slack to determine the pollutional effect, if any, of this waste discharge showed that:

(a) Individual constituent concentrations are far below selected maximum tolerance levels.
(b) The addition of the treated waste did not alter the estuarine water quality.
(c) River quality varies only slightly in close proximity to the waste outfall, and no localized accumulation of waste constituents exists.

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AERATION OF WHEY WASTES

II. A COD AND SOLIDS BALANCE

By Nandor Porges and Lenore Jasewicz

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This report summarizes recent laboratory investigations on whey aeration and supplements a previous publication (1) showing that whey wastes may be readily treated under certain conditions without nitrogen addition. Under the conditions of that experiment, sludge accumulation occurred when 1,000 mg/l of whey were oxidized in the presence of 2,000 mg/l of sludge. The series of experiments was continued, and a balance of influent and effluent material was assembled. These supplementary studies present information on COD oxidation, sludge build-up, sludge losses from the aerators, and purification potentialities.

Experimental Procedure

Two aerators were kept in operation for a period of 96 days. One aerator received natural whey; the other received the same whey supplemented with ammonia to give a COD : N ratio approaching that of dairy wastes. Temperature was maintained at approximately 30°C by submerging the glass jar aerators in a water bath. Aeration was by means of a turbine-type agitator which dispersed air supplied at the rate of 1.5 volumes per minute and provided excess aeration for the process.

In the course of the previously reported work, it was observed that a definite sludge increase was occurring, longer settling times were necessary, and that some sludge was being lost in the effluent. From that time, 35 days after the initiation of the experiment, the effluents were carefully recovered, measured, and analyzed. The COD of the starting sludge was 4,419 mg/l in the natural whey treatment tank and 4,038 mg/l in the N-supplemented tank. Over the following period of 61 days, a total of 576 g of whey was added to each aerator in 48 doses. Whey feedings were omitted over week-ends although aeration was continued.

The regimen employed was as follows:

To the 4 l of sludge which had been aerating overnight were added 12 g whey solids and 8 l water (plus 0.80 ml concentrated NH_4OH containing 175 mg N to the supplemented tank). The mixed sludge liquor was aerated and agitated for 1.5 to 2 hr prior to settling of the sludge for 1.5 to 3 hr, as necessary. All material above the 4-l mark was removed by siphon. Aeration and agitation were resumed until the next feeding period. The 8 l removed as effluent were thoroughly mixed and sampled for analysis. Since in most cases analyses could not be performed immediately, 4 drops of concentrated H_2SO_4 were added to each 40-ml sample to arrest microbial activity. These samples were refrigerated for future COD assay.

Effluents were of varying clarities; some were almost clear while others were quite turbid. Great variations were also observed in amounts of cellular material present. A 25-ml portion of the fresh effluent was immediately filtered through asbestos on a Gooch

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TABLE I.—COD Balance in a 61-Day Study in Which Dilute Whey Was Added 48 Times to Aerating Sludge

Item	Natural Whey (g)	Whey +Nitrogen (g)
Whey (2.34% H_2O)	576.0	576.0
Whey carbon	219.4	219.4
Whey COD (calculated)	585.1	585.1
Whey COD (assay)	592.1	592.1
Whey nitrogen (2%)	11.3	11.3
Nitrogen added	0	8.4
Total nitrogen	11.3	19.7
COD:N	52:1	30:1
Sludge, start COD	53.0	48.5
Sludge, final COD	74.4	75.4
Sludge increase, COD	21.4	26.9
Effluent COD	112.9	138.3
COD remaining	134.3	165.2
COD remaining	22.7*	27.9*
COD oxidized	458.8	426.9
COD oxidized	77.3*	72.1*
Filtrate COD	18.8	12.7
Possible COD removal	573.3	579.4
Possible removal	96.8*	97.9*
COD oxidized per day	7.5	7.0
COD available per day	9.7	9.7

* Per cent.

crucible. The residual material was dried at 105°C for 24 hr, cooled, weighed, and reported as effluent sludge solids. The filtrate was acidified and refrigerated for later COD determination.

Results

Table I summarizes the data and presents a COD balance on 61 days of operation. The whey used in these studies contained 2.34 per cent moisture, and the analysis on the moisture-free basis showed it to have 75.1 per cent lactose, 2.0 per cent nitrogen (12.5 per cent protein), 4.37 per cent ash, and a carbon content of 39.0 per cent. The 576 g of whey added in 48 feedings were calculated to have 585.1 g COD from its carbon content. Actual analysis by a rapid assay (2) gave 592.1 g COD which was the value used in these studies. This same amount of whey contained 11.3 g nitrogen, giving a COD:N ratio of 52:1. Nitrogen supplementation of 8.4 g in the second tank gave a total of 19.7 g of nitrogen or a COD:N ratio of 30:1 which was comparable to skim milk or dairy wastes.

Sludge accumulated in both tanks, amounting to an increase of 21.4 g COD with treatment of natural whey and 26.9 g COD in the other tank. A considerable amount of COD was present in the 8-l effluents collected by siphoning—112.9 and 138.3 g. Thus, of the 592.1 g whey COD entering the systems, 22.7 and 27.9 per cent was not oxidized, while about 75 per cent was oxidized. It should be noted that only 2 to 3 per cent soluble COD remained in the filtrate. Therefore, a potential purification of 97 per cent is possible under proper conditions of separation.

Over the 61-day period of this experiment, the average amount of natural whey COD disappearing by oxidation was 7.5 g/day from an available 9.7 g, or 77 per cent. The accumulated data on solids balance (Table II) corroborates these findings. The 25 feedings made in the last 35 days of the experiment amounted to 300 g whey solids, 78 per cent of which was oxidized. Nitrogen supplementation had a negative influence.

The available data can be used to determine the amounts of whey and sludge oxidized. First, assuming that 62.5 per cent of the available COD of whey wastes is converted to cell COD, the 9.7 g (Table I) should produce 6.1 g of cell COD by the assimilation process (3). The theoretical amount

TABLE II.—Solids Balance of Last 25 Feedings in 35 Days

Item	Natural Whey (g)	Whey +Nitrogen (g)
Whey added	300.0	300.0
Effluent sludge	65.1	83.7
Solids oxidized	234.9	212.7
Solids oxidized	78.3*	70.9*
Solids oxidized per day	6.7	6.1
Solids available per day	8.6	8.6

* Per cent.

oxidized to carbon dioxide, therefore, will be 3.6 g. Since there was a total COD of 7.5 g oxidized per day, the remaining 3.9 g were apparently lost through sludge burn-up and thus establish daily sludge oxidation rate of 5.24 per cent. An accumulation of sludge occurred equivalent to 6.1 g produced less the 3.9 g oxidized or 2.2 g COD.

The rate of whey feeding and of sludge oxidation necessary to maintain a state of dynamic equilibrium may be calculated easily. If only 7.5 g whey COD were added, 4.7 g would have been converted to cells and 2.8 g would have been eliminated as carbon dioxide. If 74.4 g sludge COD are assumed as the initial concentration, the sludge oxidation rate would have been 6.32 per cent. Daily oxidation of 10 units of whey COD should be possible by 100 units of sludge cells. The 12 g whey feedings would have required 120 g sludge COD or 96 g sludge. This sludge oxidation rate slightly exceeds the 5.5 per cent recently reported by Kountz and Forney in their study on activated sludge total oxidation metabolism (4). The value is somewhat less than that proposed by the 6-hr Warburg study on skim milk wastes by Hoover and associates (5) in which it was estimated that 10 to 20 per cent of the sludge is oxidized per day. The latter value was used by Kountz in designing a rapid ejector aeration process for the treatment of dairy wastes (6)(7).

Wuhrmann (8), in discussing the factors affecting efficiency and solids production in the activated sludge process, stated that it is theoretically possible to run a plant without any sludge production provided no insoluble and unfermentable solids are introduced with the waste. Under actual operating conditions, however, an ideal environment for total sludge oxidation rarely has been attained; and slight quantities of substances that cannot be oxidized within the aeration tank are formed. Yet, total oxidation plants are in use. The success of dairy waste aeration plants led Tapleshay (9) to the application of this type of treatment to municipal and other wastes. Purifications of 75 to 90 per cent in the presence of sludge concentrations of 3,000 to 12,000 mg/l were obtained with long periods of aeration. However, an occasional wasting of sludge is necessary. Likewise, the complete mixing activated sludge system devised by McKinney *et al.* (10) was designed to operate without production of excess sludge, yet solids are expected to increase slowly. Ettinger (11) emphasized the use of lengthy aeration times to avoid disposition of excess sludge and to avoid nitrogen supplementation. That nitrogen supplementation was not necessary is demonstrated in this current study. The effluent was withdrawn shortly after the whey had been assimilated and before extensive sludge oxidation had taken place. Additional aeration oxidized the sludge and released nitrogen to meet the demands of synthesis for subsequent assimilation and oxidation of the whey wastes.

Summary

1. COD and solids balances are presented for an extended period of whey waste aeration in which the sludge-whey mixture contained 1,000 mg/l whey.

2. An average of 75 per cent of the influent whey COD was oxidized. With proper removal of sludge from the effluent, a purification of 97 per cent is possible.

3. Although a sludge COD oxidation rate of 5.2 per cent per day was obtained, sludge accumulation occurred.

4. Nitrogen supplementation of whey waste offered no advantages in the regimen employed.

5. Calculations show a possibility of a dynamic equilibrium when 100 units of sludge are used to treat 10 units of whey, based on a 6.3 per cent per day sludge oxidation rate.

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MEETINGS OF INTEREST

Apr. 16–17 **24th Annual Conference of the Illinois Sewage Treatment Plant Operators,** Leland Hotel, Springfield, Ill.

Apr. 20–24 **Second Seminar on Biological Problems in Water Pollution,** Robert A. Taft Sanitary Engineering Center, 4676 Columbia Parkway, Cincinnati 26, Ohio. Clarence M. Tarzwell, same address.

Apr. 24 **Seventh Annual Pennsylvania Clean Streams Conference,** Abraham Lincoln Hotel, Reading, Pa. R. V. Wall, Pennsylvania State Chamber of Commerce, State Chamber Building, Harrisburg, Pa.

May 4–8 **American Society of Civil Engineers,** Hotel Cleveland, Cleveland, Ohio. W. H. Wisely, Executive Secretary, 33 West 39th St., New York 18, N. Y.

May 5–7 **Fourteenth Industrial Waste Conference,** Purdue University, Lafayette, Ind. Professor Don E. Bloodgood, Purdue University, Lafayette, Ind.

May 6–9 **12th International Conference on the Study of Waters,** Liege, Belgium. Edm. Leclerc, Centre Belge D'Etude et de Documentation Des Eaux 2, rue A. Stévart, Liege, Belgium.

May 13–15 **National Rivers and Harbors Congress,** Mayflower Hotel, Washington, D. C. William H. Webb, Executive Vice-President, 1028 Connecticut Ave., N. W., Washington 6, D. C.

July 12–17 **American Water Works Association,** Civic Auditorium, San Francisco, Calif. Harry E. Jordan, Secretary, AWWA, 2 Park Ave., New York 16, N. Y.

ORGANIZATION FOR LIQUID WASTE CONTROL IN GENERAL MOTORS CORPORATION *

By David Milne

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As in many other large organizations, the industrial waste control program of General Motors was a gradual development over the years. It was not suddenly decided that the Corporation was faced with a problem in waste control and that, therefore, a centrally organized activity should be developed to evaluate these problems and to advise and supervise the various Divisions in taking care of waste control problems. Work on the control of industrial wastes was carried on independently by the individual Divisions as the need arose.

Probably the first activity which could be described as waste control was that of the continual evaluation of manufacturing processes to minimize losses due to waste. At that time little was known about recovery of materials from wastes and the techniques and equipment available for recovery of valuable materials were rather limited.

Early Treatment Methods

Certain easily identifiable wastes of a highly undesirable nature, such as cyanides, were treated on a spot basis, and the first piece of equipment built at General Motors for waste treatment was developed to destroy cyanides. This was an application of the use of acids for conversion of cyanide salts to hydrocyanic acid and ultimate disposal of the gas to the atmosphere.

This first treatment system was established in 1934 and was simply a used plating tank fitted with a device to allow introduction of acid, and provided with ventilating fans to blow the released gas up a high stack (Figure 1). Analytical methods were not sufficiently developed at that time to make sure that all cyanides were destroyed, and occasional difficulties with the system can be traced to lack of accurate control techniques.

The next Division to build a treatment system designed it to retain all of the liquid wastes being discharged from plant processes, with the exception of strong cyanides. Recognizing that cyanides represent an unusual and specific problem in waste treatment, a separate system was installed to handle this waste by the acid destruction method (Figure 2). Other wastes were simply accumulated in large holding basins and were discharged at a controlled rate and pH to the local sewer system. This system was installed in 1938 and was considered an acceptable approach to waste control at that time.

Somewhat later, in 1941, another Division of the Corporation was faced with treatment of wastes from an enlarged plating system. As a result of consultation with other Divisions of the Corporation, with plating chemical suppliers, and with representatives of the State Health Department on what could be done to handle this increase in plating wastes, a system of regulated discharge was established (Figure 3). This method has remained in use until the present time.

These early approaches to waste control are brought out to illustrate the

* Presented at the 31st Annual Meeting, Federation of Sewage and Industrial Wastes Assns.; Detroit, Mich.; Oct. 6–9, 1958.

FIGURE 1.—First cyanide waste destruction system built by General Motors Corporation (1934).

point that each of the problems required a different approach to reach a solution. In one case there was obvious need for chemical destruction. In a second, there was need for both chemical destruction of concentrated wastes and lagooning to adjust the concentration and flow of the discharge. In the third case, it was found by group study that there was no need for chemical treatment of the wastes but that consideration of the over-all situation permitted the plant to discharge its wastes in a manner satisfactory to the local authorities and at the least cost to the industry.

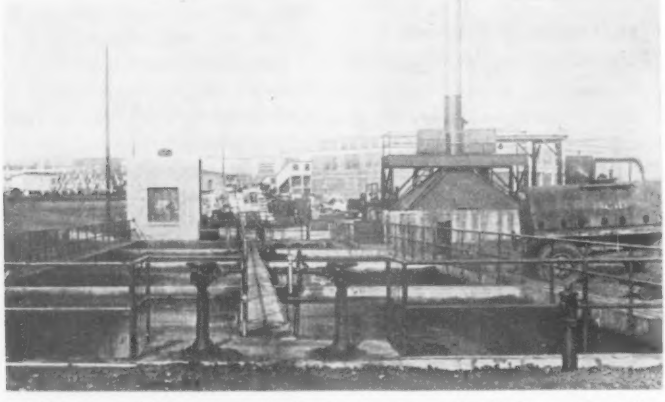

FIGURE 2.—Waste accumulation basins for neutralization and settling of wastes. Cyanide destruction system is in right background (1938).

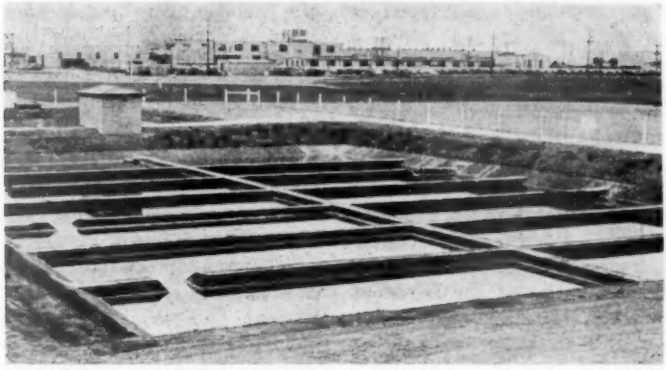

FIGURE 3.—Lagoons used for regulated discharge of concentrated and dilute plating wastes and cooling waters.

The examples also point out that while the early approaches to waste control were based on individual Divisional thinking, the group study technique used by the third Division proved to be more satisfactory in that it brought into the picture the combined efforts of the plating chemical supplier, of other Corporation chemical engineers who had at least some limited experience with waste control, and the close cooperation and approval of the State Health Department.

From the end of 1941 until well into 1945, active development of waste treatment systems was suspended due to preoccupation with war production. While active waste control work was suspended, further thinking along the lines of the need for waste control and how the Corporation might be better organized for effective and economical waste control was still continuing.

Formation of Industrial Waste Committee

In 1945, therefore, the first step toward this goal was taken in the development of the General Motors Industrial Waste Treatment Committee under the sponsorship of the GM Production Engineering Section. This committee was originally made up of seven men selected from certain Divisions and staff activities which had interests in waste treatment. The need for such a move was evident and interest in the Corporation grew very rapidly. From a group of seven, meeting somewhat irregularly to discuss waste treatment, the committee expanded to 46 men, representing 26 staff activities or Divisions, all interested in what techniques were available to their Divisions to help them solve their particular problems.

During these early years the discussions which developed in the committee served to emphasize the fact that the main interest and value of the program were not in the direction of treatment of wastes, but in learning how to control these wastes so that treatment costs could be kept at a minimum and so that valuable materials which would otherwise be lost could be recovered for reuse. Realization of this objective prompted the committee to change its name in 1947 to the General Motors Industrial Waste Control Committee.

Activities of the Committee

Bases of Activity

At first a review of earlier work within the Corporation was made. This was done mainly to stimulate thinking and to allow others to use

information previously developed in waste control.

The second phase of the Committee's activities was to study the restrictions being placed on discharge of wastes by various control authorities. To do this the Committee scheduled discussions with the chief engineers of the health departments of several states, and with the directors of federal and interstate control agencies. These meetings served to focus the attention of the Divisions on the fact that restrictions were being developed, and in some cases being written into the law, for their guidance in the control of waste solutions. It also emphasized that the surge of activity to correct the polluted condition of streams was not temporary.

Emphasis was placed on the fact that waste control should be considered a necessary part of each manufacturing process, and that it was advantageous to engineer waste control techniques into a process at the time it was installed. The program of the Industrial Waste Control Committee at that time included distribution of published material on pollution and its control to Divisional management to keep them abreast of progress.

The third phase of the work of the Committee was to study what had been done by other industrial organizations in the metal working field to handle wastes. This was done by encouraging Committee members to attend meetings of national associations which included sessions on waste control as part of their program, and either to schedule speakers from other industries to appear at the Committee's meetings or to have the entire Committee visit some organization which had done an outstanding job of controlling its wastes.

The work done by the Committee during this time resulted in the gradual development of a backlog of information and experience for the Committee members. As this program continued, more and more of the Committee members were being faced with the problem of making decisions on the kind of waste control needed for their plants. In general, and because of the experience gained through Committee participation, the decisions made were sound for the kinds of wastes at hand and in view of the available information.

The fourth phase of the Committee's history was a review of the work done by General Motors in industrial waste control since organization of the Committee. This was one of the most valuable phases of the Committee's existence. Those who had pioneered in the design and installation of waste treatment plants were now in a position to advise other Divisions on the basis of their experience with the early treatment plants. The general attitude was "On the basis of what I know now, what would I do if I had to build this waste treatment system over again?" Committee members described their installations, and provided an honest evaluation of the good points and bad points of the equipment which they had to build, operate, and maintain. Using this critical approach, Divisional engineers were able to provide those whose treatment requirements developed later in the program with some of the most practical and valuable advice available to them.

In the interest of industrial waste control, the Corporation has sponsored a total of 81 meetings of the Industrial Waste Control Committee and its subsidiary groups since its formation in 1945.

All of this activity resulted in the fifth and present phase of operation of the Industrial Waste Control Committee. In this phase a strong but small Industrial Waste Control Advisory Group has been established. This group is made up of individuals who have detailed and expert knowledge of the field of waste control, and includes men who have designed, built, and operated extensive waste treatment facilities in different areas of manufacturing. It also includes men who

have worked closely with national and interstate organizations in the development of waste control philosophy and legislation, and men who have administrative responsibility for the control of industrial wastes in Divisions having from 20 to 30 operating plants.

With this strong Advisory Group, the General Motors Corporation is now in a position to offer advisory service to any of its Divisions in need of help. Part of the program is to make sure that the Divisions are kept aware that control of wastes is an activity requiring continued review to obtain greatest value.

The continual need for keeping the Corporation as a whole informed of new developments in waste control is recognized. To do this the Advisory Group arranges for at least two conferences of Divisional personnel each year to study phases of industrial waste control which are of current value. A typical conference will have one of the Division's waste handling and treatment facilities discussed in detail by one of the individuals responsible for the design, installation, and operation. Inspection of the facilities will follow. An outside expert will be brought in to discuss a specialized phase of industrial wastes. Several Corporation professional men will report on individual treatment methods or problems at various Divisions or of interest to Corporation activities. An open discussion on operating problems and new developments will encourage all in attendance to participate.

Outside Consultants

In general, the Advisory Group recommends that any Division faced with a waste control problem secure the service of a competent outside consultant to determine the direction of its waste control effort. At first glance this may seem surprising in view of the wealth of experience available within the Corporation. Each member of the Advisory Committee is, however, an engineer with heavy commitments to his own Division, and it is rarely possible to have him assigned to another Division in the capacity of a consultant. Another reason for this attitude is that in the study of a waste control problem, including a survey of the wastes involved, determination of possible conservation measures, selection of treatment methods, and development of treatment equipment, design and installation techniques are usually beyond the capacity of a member of a Divisional staff who is also pressed with other responsibilities.

An outside consultant brings to the job the experience gained in the study and solution of problems in other related manufacturing organizations. With the help of the Division's technical staff, he can secure the information needed to permit a relatively accurate evaluation of the waste problem. He knows from experience what things to look for and what things are usually overlooked in a survey made by industrial people. His job is to know what treatment methods are the most satisfactory under a multitude of different conditions, and to be able to select the right design and capacity of equipment to handle these conditions. He usually has a good working relationship with the control authorities and will act as a spokesman for the Division in negotiations with these authorities.

Within the Corporation, however, a check and balance system is provided in that while the employment of a consulting firm is recommended to secure information on waste control, a recommendation is also made to the Division that the findings of this consultant be reviewed by the Industrial Waste Control Advisory Committee in the presence of the consultant and the Division's engineers. This brings into play the combined experience of the Advisory Group in the practical handling and operation of similar waste control systems. In nearly all cases this check of the consultant's work has resulted in mutual agreement to modify some of the engineering approaches to

the problem, and has in all cases resulted in a more satisfactory installation of treatment or control equipment.

Design and Construction

Another phase of the General Motors Corporation activity in the waste control field has developed within the last 10 years and is confined almost entirely to the area of design and construction of waste treatment plants. This is the work handled by the Argonaut Realty Division which was established to design and build manufacturing plants for the Corporation. The Divisions of the Corporation realized that this organization could also help in the design and construction of waste treatment plants, and several Divisions have made use of Argonaut for this purpose. Part of the present program of Argonaut Realty Division is in helping the other Divisions determine what is needed for waste control. It then undertakes to design treatment facilities, and to supervise construction of the waste control plant.

It should be emphasized that General Motors is a highly decentralized organization and no pressure is placed on the Divisions to follow any predetermined course of action. The possibilities for most effective action on waste control problems are made clear to the Divisions and their choice of method for solution of the problem will depend on local conditions, on the availability of consulting help, and on the nature of the waste control problem involved. A Division may elect to handle the entire waste control problem by itself in the event it has personnel capable and experienced enough to do the job satisfactorily. On the other hand, the Division may turn the entire job over to an outside consulting firm on a turnkey basis, and depend on that firm to build a waste treatment facility which will meet the requirements of the Division. Again, the Division may turn to Argonaut Realty Division for help in the solution of its waste control problem, and ask that organization to solve the entire problem in much the same way as it would an outside consultant.

In most cases the Divisions will also seek the help of the Industrial Waste Control Advisory Group to review the recommendations made for the solution of their waste control problem. This has resulted in a strong but exceedingly flexible activity toward solution of waste control problems in the Corporation. It has resulted in the construction of minimum facilities, such as a single tank for destruction of concentrated cyanides, to the building of some of the largest industrial waste control plants in the country.

Principles

One phase of the industrial waste control activity of the Central Office should not be overlooked. Along with the education of technical and management people in the Corporation on what had to be done in control of wastes, a program of complete cooperation and, in some respects, education of regulatory authorities in the States and in the Federal Government was established. This program was designed to make sure that the men in these organizations knew exactly what was going on at General Motors in the area of waste control. The program has helped tremendously in securing an atmosphere of cooperation, good will, and mutual understanding. It is maintained, however, that the existence or nonexistence of state or federal regulations should have no effect on application of waste control measures in the Corporation. As a matter of fundamental principle it is believed that Corporation plants should not pollute the waters of the community and that each organization should take every step within reason to be a good citizen of its community.

Installations

It is of interest to look at some of the work done in the Corporation in

the area of waste control. Obviously procedures and treatment plants cannot be discussed in detail. Waste treatment, recovery, or control facilities have been built in over 95 plants at a cost of about $30 million for initial construction. A review of three installations will illustrate Divisional approach to conservation of materials, treatment of only one waste, and treatment of all wastes from metal working operations.

Materials Conservation from Plating

Although vacuum evaporation has been applied successfully to the recovery of copper plating solution, nickel plating solution, and principally chromium plating solution for a number of years, the Corporation only recently has made use of evaporators operating at atmospheric pressure.

One of the Divisions has installed atmospheric evaporators for recovery of chromium and nickel plating solutions from dilute reclaim rinses, and has had considerable success with their operation. Figure 4 shows equipment used in the nickel recovery system. The system includes (a) a holding tank (for continuous treatment, if desired), (b) a recirculation tank with pumps, (c) an evaporator tower, (d) an air blower, and (e) heat exchangers. Although the system may be operated continuously, the activity has been confined to batch treatment.

Nickel solution carried over on parts after nickel plating is allowed to concentrate in a reclaim rinse to approximately 10 oz/gal then is transferred to the recovery system recirculating tank. Approximately 1,000 gal of this reclaim solution is treated as a batch. At the beginning of the cycle the solution is pumped from the recirculating tank through heat exchangers to raise the temperature of the solution to 175°F. From the heat exchangers the solution is pumped to the top of the evaporator tower where it is permitted to trickle through berl saddles against an upflow of air supplied by the auxiliary blower. In approximately 10 hr the original 1,000 gal is concentrated to about 300 gal with a concentration of 35 oz/gal single nickel salts. The recovered solution is added to the nickel plating tank.

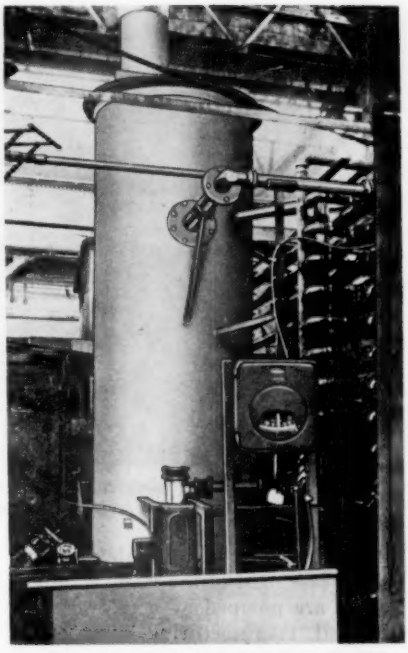

FIGURE 4.—Typical apparatus for atmospheric evaporation and concentration of plating wastes.

One presumed advantage of the atmosphere evaporator over the vacuum evaporator as applied to nickel solutions is that the wetting agents do not have to be destroyed. However, actual experience has indicated that some foaming does occur.

A disadvantage is that no deionized water is produced by atmosphere evaporation. On the other hand, no cooling water is required. Operating costs are similar.

Treatment of a Single Waste

A second direction of activity is treatment of a primary waste, with in-

FIGURE 5.—Holding tanks, oil storage tanks, and primary clarifiers at a large oil waste treatment plant.

cidental recovery of a usable material. In this case most of the waste solutions treated are pumped by a relay system from all manufacturing areas to a centrally located disposal plant. Wastes pumped to this plant are primarily oils, but include some greases, alkalies, paint spray booth solutions, chromic acid, and phosphate wastes. Here the wastes are collected in either of two 750,000-gal collection tanks to be skimmed and then processed as a batch (Figure 5).

Clarification is accomplished in two stages. Chemicals used in the primary clarification include waste pickle acid (hauled by truck to the disposal site and stored in 10,000-gal lined tanks), alum, and sometimes ferrous sulfate. Chemicals used in final clarification in-

FIGURE 6.—Second stage treatment tanks and sludge drying beds in an oil waste treatment plant.

FIGURE 7.—Characteristic sludge bed produced from oil waste treatment plant.

clude lime, ferrous sulfate, Guartec (an organic coagulant derived from the Guar Bean), and sometimes alum. Figure 6 shows some of the equipment used in this operation.

Sludge is dried either by vacuum filtration or on sludge beds (Figure 7). Final disposal is by land fill. Wastes hauled by truck to this plant include sulfuric acid anodizing solutions and spent pickle wastes (HCl, H_2SO_4, H_3PO_4, and HNO_3). Primary wastes are the alkaline and oily solutions. The oil, skimmed from the collection tanks, is treated with concentrated sulfuric acid plus live steam injection. The clarified oil has a water content of one per cent by volume or less. This oil has been burned as a fuel oil, sold as a high grade salvaged oil, and with additives made into a high grade cutting oil.

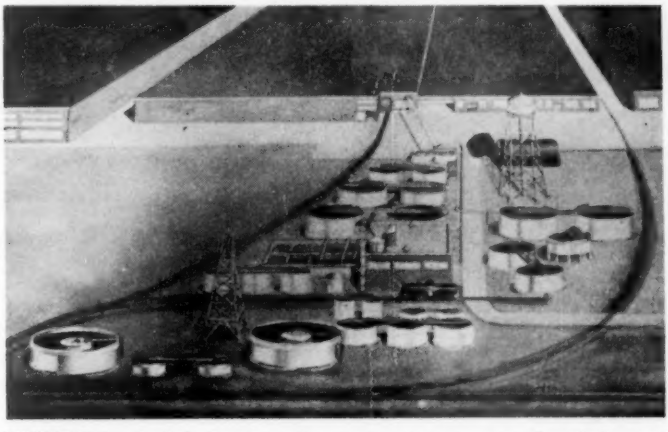

FIGURE 8.—Artist's drawing of waste treatment system for plating and oil wastes from a large automotive manufacturing and assembly plant.

General Metal Working Wastes

The third example is that of a treatment plant designed to handle a wide complexity of wastes from metal working, including plating, cleaning, oils, and pickling wastes. Treatment facilities previously located in the various manufacturing plants at the Division have been replaced by a large centrally located waste treatment plant (Figure 8). Waste solutions are pumped from sumps located in the manufacturing areas to the waste treatment plant through six separate influent waste lines: (a) strong cyanide wastes, (b) dilute cyanide wastes, (c) strong metallic wastes, (d) weak metallic wastes, (e) alkali-acid wastes, and (f) alkali-oily wastes. Each influent line flows into two holding tanks, and each tank has a capacity equal to the total flow for one operating day. The waste plant was designed to treat the contents of each holding tank in 16 hr.

Each of the 12 holding tanks is equipped with a mixer, which helps to maintain a homogeneous solution for treatment (Figure 9). The waste solutions flow from the holding area to the treatment systems closely grouped near the main control and operating building. This building houses the electronic control and monitoring equipment, and other units such as feeders, filters, etc.

The strong cyanide wastes are added in small quantities to the dilute cyanide wastes. Tank car quantities of chlorine gas are required for the alkaline chlorination method used. Liquid chlorine is piped from the tank car to the evaporators and the chlorine is then injected into the wastes.

After treatment the solution is pumped to three polishing tanks shown in Figure 10. These tanks serve as intermediate holding tanks to insure that the treatment has been completed. If, for some reason, the solution requires further treatment it is pumped to the main holding tank. If no further treatment is required the solution is pumped to a final clarifier.

Alkali-acid wastes flow from the holding tank to a mixing tank where acid or alkali is added automatically to maintain the effluent within the desired pH range. Strong metallic wastes

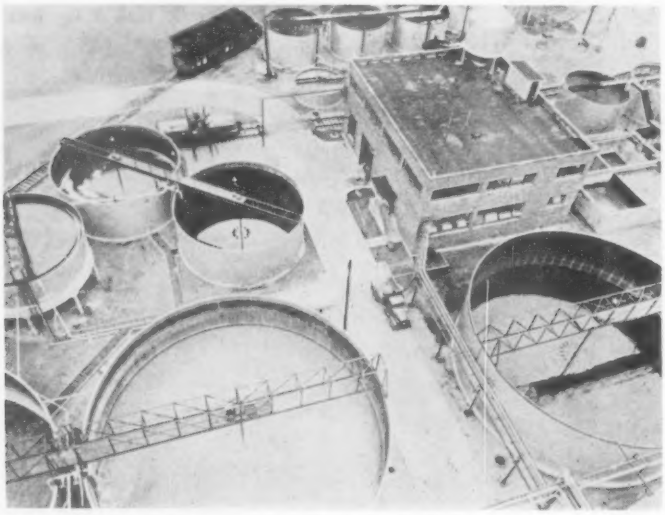

FIGURE 9.—Overhead view of the control building and some of the treatment tanks in the plating and oil waste treatment system.

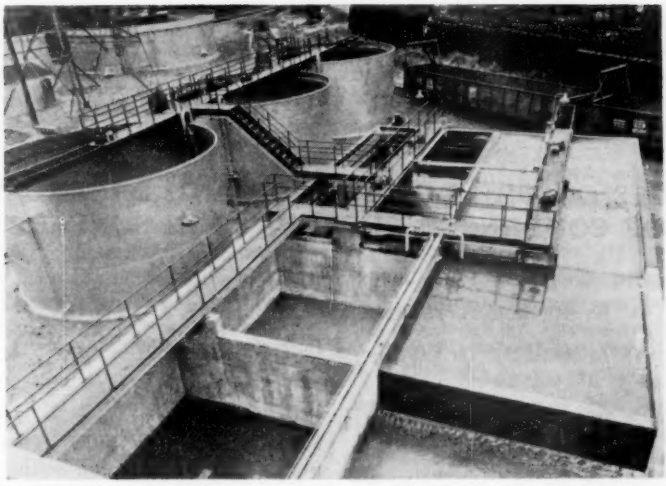

FIGURE 10.—Reaction basins and polishing tanks for alkali-chlorine treatment of cyanide wastes. Final clarification tanks are in far left background.

(principally chromium-containing solutions) are added in small quantities to the weak metallic wastes and are treated by the reduction of hexavalent to trivalent chromium with sulfur dioxide. Alkali-oily wastes from the manufacturing plants are pumped to a primary clarifier where free oil is skimmed and the solids are removed. From the clarifier the effluent flows to the two holding tanks in this system. From the holding tanks the oil-containing solutions flow to an oil-flotation unit where air and coagulants are used. The effluent from the oil-flotation process flows to a final clarifier while the oil-containing floc is removed and dewatered on vacuum filters. Final clarifiers receive the effluent from the various treatment processes and serve as a final point of treatment prior to discharge of the wastes.

Summary

This paper traced the development of a system for providing engineering advice to divisions of a large corporation toward the solution of industrial waste problems. Starting with a brief historical review of the work done by the General Motors Corporation in waste control, it then proceeds to outline the kind of waste control advisory and engineering activity found to be most practical for the decentralized structure of the Corporation. It includes a discussion of the organization of an industrial waste control committee for the study of waste problems and its use as an advisory group toward the solution of problems in the various General Motors Divisions. The assignment of a central General Motors engineering activity to design and construction of industrial waste treatment plants is also described, together with an explanation of how these activities cooperate toward the solution of Divisional problems. The paper gives a brief description of three widely different waste treatment operations in General Motors Corporation.

Stream Pollution

STUDIES ON THE OCCURRENCE AND DEGRADATION OF CONDENSED PHOSPHATE IN SURFACE WATERS *

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Background

It is logical to expect that the rapid increase in the use of synthetic detergents during the past ten years has been accompanied by the presence of greater quantities of synthetic detergent compounds in sewage effluents and in surface waters. While numerous isolated reports of the concentrations of synthetic detergents in sewage and surface waters have appeared, there has been relatively little investigative research devoted to establishing the levels of synthetic detergent components in sewage effluents and in surface water supply sources. It is known that present-day synthetic detergents contain, as relatively major components, the inorganic condensed phosphate salts, sodium tripolyphosphate (STP) and tetrasodium pyrophosphate (TSPP). About 50 per cent by weight of most of the built detergents sold today is composed of a combination of STP and TSPP.

It has been suggested that the condensed phosphate compounds of synthetic detergents might find their way through sewage treatment plants and surface waters and into water supply intakes. Since STP and TSPP are known to possess inherent peptizing and defloculating properties, their presence in water supplies could conceivably produce interferences with normal coagulation and sedimentation operations in conventional water treatment processes. The studies reported in this paper are concerned with: (a) the concentrations of condensed phosphates found in sewage effluents and in surface waters in Illinois, and (b) the persistence of condensed phosphate compounds in natural waters.

Phosphates in Sewage and Surface Waters

The determination of condensed phosphates attributable to synthetic detergents is complicated by the fact that the phosphates in sewage effluents may originate from sewage, water treatment operations, or miscellaneous industrial operations, as well as from household synthetic detergents. Furthermore, phosphate compounds in surface waters are known to occur in part from natural drainage of agricultural land.

Rudolfs (1) reported an average phosphate concentration in raw sewage of 5.2 mg/l as P_2O_5 in 1947. The average concentration in effluents from biological treatment was 0.5 mg/l as P_2O_5. Rudolfs indicated that per capita phosphate contributions from domestic raw sewage were from 3.3×10^{-3} to 7.5×10^{-3} lb/day as P_2O_5. Sawyer (2) calculated that the con-

* Presented at the 31st Annual Meeting, Federation of Sewage and Industrial Wastes Assns.; Detroit, Mich.; Oct. 6–9, 1958.

tribution of phosphates used in the detergent and water softening industry during 1950 amounted to 10×10^{-3} lb/day/cap as P_2O_5. Estimates by the Association of American Soap and Glycerine Producers indicated a synthetic detergent consumption of 16 lb/cap for the year 1955. This corresponded to a contribution of 12×10^{-3} lb/day/cap as P_2O_5 to sewage by household synthetic detergents alone.

The contribution of phosphate to surface waters by agricultural drainage in the Madison, Wisconsin, area was investigated by Sawyer (3). He reported total phosphorus land drainage of approximately 1.6 lb/day/sq mile, of which approximately 75 per cent was organic. The effects of land drainage on water quality were treated by Silvey (4), who discussed phosphorus transformations in cultivated soils, observing that organic phosphorus in plant leaves may be oxidized to soluble phosphates. Sudden additions of water—through rainfall, for example—could then wash phosphates to the streams.

A portion of the raw data on phosphates in surface waters, also presented in this paper, was reported by Dietz and Harmeson (5), who concluded that the average total phosphate concentration in Illinois surface waters was 0.648 mg/l as P_2O_5. Solely on the basis of stream analysis data, they estimated that the phosphate contribution from domestic sewage would range from 7.07×10^{-3} to 87.3×10^{-3} lb/day/cap.

Degradation of Condensed Phosphates

Because the "builders" or supplementary compounds in commercial synthetic detergents include condensed phosphates, these compounds are of particular interest as they appear in sewage effluents and receiving waters. Of interest in this study was the property of such compounds to undergo what is referred to as hydrolysis, hydration, reversion, or hydrolytic degradation. That is, these compounds have the tendency to react with water to form, ultimately, orthophosphate. This property, as well as others, has been discussed in several articles (6) (7) (8). In summary, it has been found that the rate of hydrolytic degradation of condensed phosphates is influenced by many factors. These include: temperature; pH; enzymes; colloidal gels, *e.g.* hydrated oxides of iron and aluminum; complexing cations, *e.g.* calcium; concentration; and the ionic environment of the solution.

Of interest in this study was the investigation reported by Sawyer in 1952 (2), who studied the degradation of STP and TSPP in domestic sewage. Using 10 mg/l phosphorus or 22.9 mg/l as P_2O_5 of STP and TSPP separately, Sawyer found STP was degraded much more slowly than TSPP. He also observed a greater rate of degradation of both compounds at 20°C as compared to 5°C. Although it was not indicated, the "half life"* of TSPP in sewage at 20°C appeared to be in the order of 15 hr.

The degradation of STP and TSPP was studied by Smith, Cohen, and Walton (9), using natural waters. They found that Ohio River water, to which STP was added equivalent to 20 mg/l of phosphate, gave half life values of 240, 60, and 20 days at storage temperatures of 5°, 20°, and 35°C, respectively. In a similar experiment using TSPP, the half life results were 220, 120, and 45 days. Although these data indicate that in general STP had a greater rate of degradation than TSPP, it should be noted that the two experiments were conducted using two different Ohio River water samples and, as a result, differed in chemical and physical characteristics. In a third experiment, using TSPP and a "local stream water" which was a harder water, the half life at 5°, 20°,

* The time necessary for 50 per cent of the condensed phosphate to be degraded to orthophosphate.

and 35°C was found to be 310, 180, and 75 days, respectively.

Using various species of the plant kingdom, Karl-Kroupa *et al.* (8) studied the degradation of STP under aseptic conditions. The medium used in this study was sterile distilled water to which STP was added in an amount equivalent to 5.5 mg/l phosphorus or 12.6 mg/l P_2O_5. The organisms studied were pretreated before inoculation into the test solution, so as to be pure cultures. With the exception of *Escherichia coli*, all of the organisms were in a resting condition. All of the systems showed a lag period or induction time before active degradation of the STP occurred. The half life of STP in the various systems containing different organisms varied from 19 hours for *Allomyces* to 123 hours for *Elodea*. The control, which consisted of sterile distilled water plus STP, showed no change in 300 hours (12.5 days). According to the authors, these results indicated that the accelerated rate of degradation of STP in the systems containing the test plants was due to an enzymatic catalysis.

Experimental Methods

General

The survey of Illinois surface waters consisted of three phases:

1. Sampling of lakes and reservoirs, believed to be relatively free of domestic pollution.
2. Sampling of stream sources in the major Illinois river basins, suspected to contain significant amounts of treated and untreated wastes.
3. Continued sampling at seven stream locations in the Kaskaskia River basin.

The over-all survey continued from August 1955 to June 1957. Figure 1 indicates the lake, reservoir, and stream sampling locations in Illinois.

Samples were collected from eight lake and reservoir locations in Illinois

FIGURE 1.—Lake, reservoir, stream, and sewage treatment plant effluent sampling locations in Illinois.

in order to determine background phosphate levels in waters free of significant domestic pollution.

Selection of locations for the general survey of Illinois streams was based on information pertaining to the location of water and sewage treatment facilities in Illinois. River basins included in this survey were the Embarrass, Illinois, Kankakee, Kaskaskia, Little Vermilion, Little Wabash, Mississippi, North Fork of the Vermilion, Salt Fork, Sangamon, Vermilion, and Wabash. Twenty-seven samples were collected during this stream survey.

Because of the desirability of continued sampling of the same surface waters in order to establish the prevailing phosphate levels, it was decided to make a comprehensive survey of one river basin. Such a survey would define the phosphate levels existing for the particular stream

under known conditions of rainfall, stream discharge, agricultural drainage, and sewage discharge. The Kaskaskia River was chosen for this comprehensive survey because of its convenient location in relation to the laboratory, the existence of United States Geological Survey stream gaging stations at the sampling locations, the existence of rain gaging stations throughout the watershed, and the availability of hydrological and agricultural data for the watershed area.

The watershed of the Kaskaskia is the second largest in the State of Illinois and covers 5,670 sq miles. It extends from the center of Champaign County in a southwesterly direction to the Mississippi River near the city of Chester. Figure 1 shows the location of the Kaskaskia River.

Sampling Program

Seven stream stations were selected for a program of periodic sampling. These stations were located at Bondville, Ficklin, Shelbyville, Vandalia, Carlyle, and New Athens. Two stations were selected at Ficklin: one above and one below the waste effluent of a large industrial establishment. A total of 125 stream samples were collected during the Kaskaskia survey. The survey covered the period from April to December 1956.

The chief purpose in determining the phosphate content in sewage effluents during the Kaskaskia survey was to establish what portion of stream phosphates could be attributed to synthetic detergents. Also of interest were the relative proportions of orthophosphate and inorganic condensed phosphates in sewage effluents, because of the concurrent investigation being conducted into the degradation of condensed phosphate.

Three sewage treatment effluents were sampled periodically during the Kaskaskia survey: Southwest Champaign, Arthur, and Sullivan. Sewage flows or water pumpage records were obtained at the time of sampling in order to utilize analytical data for computation of per capita quantities of phosphate in the effluent. A total of 42 sewage effluent samples were analyzed for phosphate concentration during the Kaskaskia survey. In addition, effluent samples were collected at the Elmhurst treatment plant on seven different dates. This is the northernmost sampling location shown in Figure 1.

Rainfall, Stream Flow, and Cultivation

Because the concentration of phosphates from synthetic detergents found in surface waters depends on the volume of diluting stream flow available at a particular time, it was desirable to know the hydrologic conditions prevailing during periods of sampling. Since it was expected that phosphate materials would be contributed from agricultural drainage, it was also important to study the occurrence of peak rainfalls and peak stream discharges in relation to stream phosphate concentrations. Daily rainfall data at several gaging stations throughout the State of Illinois were obtained from the Weather Bureau, U. S. Department of Commerce. Three gages in proximity to sampling stations were selected at Urbana, Tuscola, and Windsor. These gage locations were chosen to correlate with phosphate concentrations at Bondville, Ficklin, and Shelbyville, respectively. In general, the years 1955 and 1956 were dry years in relation to the long term average for the State of Illinois. Rainfall during 1955 was 6 per cent, and that for 1956 was approximately 23 per cent below normal.

Daily average discharge records at each of the Kaskaskia River sampling points were provided by the United States Geological Survey. Data were available for the entire sampling period, and also for the period of record. A comparison of monthly stream dis-

charge during 1956 with the long-term average monthly discharge for Shelbyville is presented in Figure 2. A study of the complete period of record at Shelbyville indicated that the average discharge was 880 cfs. The average discharge for the 1955–56 water year was 467 cfs.

Data on the extent of land cultivation in the Kaskaskia River basin was obtained from the Illinois Assessor's census and the Preliminary Census of Agriculture, U. S. Department of Commerce. Populations tributary to each Kaskaskia sampling station were determined. Table I lists data from the Kaskaskia River Survey.

Sample Handling

In the water and sewage surveys, the samples collected for the determination of phosphate concentration

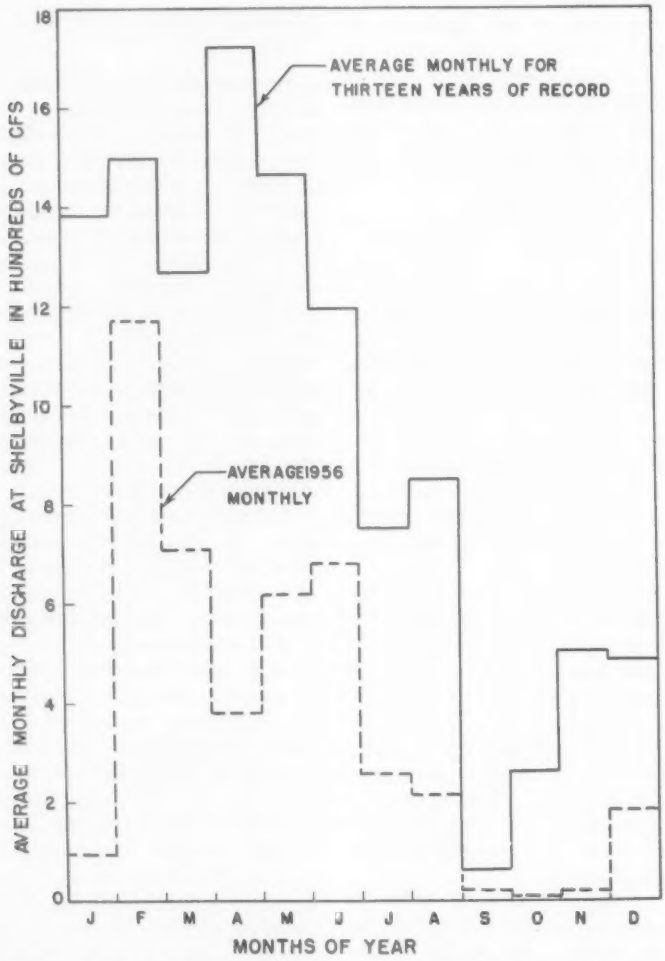

FIGURE 2.—Relation of long-term average monthly discharge to 1956 average monthly discharge at Shelbyville.

TABLE I.—Descriptive Data and Average Analytical Results, Kaskaskia River Survey April to December 1956

Station	Mile	Tributary Population	Total Drainage Area (sq miles)	Per Cent Cultivation	No. of Samples	Mean P_2O_5 (mg/l)		
						Ortho-phosphate	Ortho-phosphate + MIC	MIC
Bondville	0	0	12.3	86.0	27	0.113	0.163	0.050
Ficklin A	28	820	125	86.2	24	0.288	0.399	0.111
Ficklin B	29	820	127	86.2	25	0.144	0.543	0.399
Shelbyville	103	6,670	1,030	81.7	25	0.392	0.677	0.285
Vandalia	153	12,850	1,980	76.0	10	0.136	0.343	0.207
Carlyle	208	18,320	2,680	68.9	7	0.126	0.243	0.117
New Athens	273	90,240	5,220	76.8	7	0.200	0.430	0.230
Mean	—	—	—	—	—	0.200	0.400	0.200

were placed in polyethylene bottles and were iced during transit from the sampling point to the laboratory. The sample temperature was recorded at the time of collection, and dissolved oxygen samples were fixed to allow the titrations to be performed at the laboratory. Phosphate, hardness, alkalinity, turbidity, dissolved oxygen, and pH were determined for each sample.

To study the degradation of condensed phosphates, various lake, reservoir, and stream waters were collected and transported to the laboratory for storage. Following the analysis of the water sample for its physical and chemical composition, the sample was pretreated in accordance with the particular conditions of the experiment. Where the effect of plankton and soil particles was to be studied, one-half of the collected sample was finally filtered through membrane filters or filter paper (Whatman No. 1). Although aseptic membrane filtration was tried, it was found that bacteriological contamination occurred during either the pretreatment processing or the subsequent opening of the storage bottles for the purpose of sampling.

When filtration was employed, both the filtered and non-filtered water was divided into three portions. The six portions were placed in sterile 4-l serum bottles and brought to 29°C. A calculated amount of a sterile solution of condensed phosphate was then added to each portion and the concentration immediately determined.

In this study, the condensed phosphates used included: reagent grade tetrasodium pyrophosphate (TSPP); and sodium tripolyphosphate (STP). The STP (hexahydrate) was purified from a commercial grade by recrystallization, after Quimby (10).

Each portion, containing the known amount of either STP or TSPP, was stored in a constant-temperature room maintained at 29°C under conditions of quiescence, semi-quiescence, or turbulence. Turbulent conditions were produced by constant agitation using a mechanical shaker. Degradation of the condensed phosphate was followed by frequent analysis of the orthophosphate and ortho-plus-condensed phosphate content in each sample during the storage period.

All of the results on degradation have been expressed in terms of half life. The half life, in each storage study, was determined by plotting the per cent condensed phosphate remaining against storage time.

Analytical Methods

Analyses of orthophosphate P_2O_5 and hydrolyzable P_2O_5 in surface waters and sewage effluents were made by running a colorimetric determination on the sample before and after acid

TABLE II.—Phosphate Concentrations, Kaskaskia River, June 3, 1957

Source	Orthophosphate P_2O_5 (mg/l)	Orthophosphate Plus MIC* P_2O_5 (mg/l)	Total P_2O_5 (mg/l)
Bondville	0.05	0.06	0.09
Above Ficklin	0.14	0.16	0.19
Below Ficklin	0.14	0.23	0.31
Shelbyville	0.18	0.24	0.28

* MIC is defined as Maximum Inorganic Condensed.

hydrolysis. A modified extraction and hydrolysis procedure based on the technique originally published by Martin and Doty (11) was used. In the procedure, phosphomolybdate is extracted with a benzene-isobutyl alcohol mixture and reduced with stannous chloride to give a blue color which is measured colorimetrically.

Orthophosphate P_2O_5 is obtained by running the colorimetric determination directly on the sample. Hydrolyzable P_2O_5 is obtained by boiling an acidified solution of the sample, running the colorimetric determination, and subtracting the previously determined orthophosphate value.

Committee research by the Association of American Soap and Glycerine Producers (12) has established that the acid hydrolysis step picks up a portion of the organic phosphates in surface waters. This is brought about by the hydrolysis of P-O-P bonds in organic compounds. Thus, the determination of inorganic condensed phosphate in surface water and sewage samples by the method used throughout these studies yields results which are equal to or greater than the true value, depending on the amount and nature of organic condensed phosphates present. In the results and discussion, hydrolyzable condensed P_2O_5 is referred to as maximum inorganic condensed P_2O_5 (MIC).

The organic phosphate can be determined by wet-ashing, followed by the colorimetric determination. Wet-ashing effectively accounts for total P_2O_5, which includes all P_2O_5 in organic compounds (12).

All other analytical determinations were carried out in accordance with "Standard Methods" procedures (13).

Results

Organic Phosphates in Stream Samples

Samples were collected at four locations on the Kaskaskia River on June 3, 1957. In addition to the usual analyses for orthophosphate P_2O_5 and orthophosphate plus maximum inorganic condensed P_2O_5 (orthophosphate plus MIC), the total P_2O_5 of each sample was determined by wet-ashing. The results are shown in Table II. The data indicate the presence of organic phosphate in all samples.

Survey of Lakes and Reservoirs

Results for nine samples collected at eight lake and reservoir sources appear in Table III. The mean value of orthophosphate plus MIC P_2O_5 was 0.081 mg/l P_2O_5. The mean orthophosphate was 0.036 mg/l P_2O_5. The average MIC P_2O_5 was 55 per cent.

General Survey of Illinois Streams

The analytical results for 27 samples collected during the general stream survey are presented in Table IV. The average phosphate content

TABLE III.—Phosphate Content of Samples from Lake and Reservoir Sources in Illinois

Source	Phosphate as P_2O_5 (mg/l)	
	Orthophosphate	Orthophosphate Plus MIC
Bloomington	0.018	0.226
Danville	0.108	0.195
Danville	0.091	0.113
Decatur	0.016	0.036
Kincaid	0.000	0.000
Mattoon	0.000	0.000
Paris	0.026	0.044
Salem	0.066	0.115
Springfield	0.000	0.000
Mean	0.036	0.081

TABLE IV.—Analytical Results for General Survey of Illinois Streams

Source	P_2O_5 (mg/l)	
	Ortho-phosphate	Ortho-phosphate Plus MIC
Embarrass River:		
Oakland	0.013	0.025
Charleston	0.033	0.076
Newton	0.076	0.109
Illinois River:		
Grafton	0.541	1.551
Kankakee River:		
Kankakee	0.073	0.058
Kaskaskia River:		
Vandalia	0.334	0.706
Carlyle	0.371	0.708
Mascoutah (SC)	0.584	1.560
Freeburg (SC)	2.899	3.402
New Athens	0.380	0.788
Evansville	0.467	0.786
Little Vermilion River:		
Georgetown	0.101	0.082
Little Wabash River:		
Flora	0.061	0.113
Clay City	0.058	0.113
Fairfield	0.077	0.148
Mississippi River:		
Dallas	0.101	0.338
Nauvoo	0.65	0.531
Hamilton	0.157	0.400
Warsaw	0.227	0.603
Quincy	0.310	0.654
Alton	0.621	0.726
E. St. Louis	0.321	0.435
E. St. Louis	0.587	0.715
Chester	0.564	1.352
Vermilion River:		
Pontiac	0.062	0.073
Streator	1.329	1.299
Wabash River:		
Mt. Carmel	0.095	0.149
Mean	0.411	0.657

of these samples is considerably higher than for the lake and reservoir samples. This was to be expected, as the streams sampled were generally believed to receive significant amounts of domestic sewage. The average orthophosphate content of all samples was 0.411 mg/l P_2O_5. The average orthophosphate plus MIC content was 0.657 mg/l P_2O_5. The average MIC P_2O_5 was 0.246 mg/l, or 38 per cent. The highest value of MIC P_2O_5, 1.01 mg/l, was observed at Grafton on the Illinois River. The highest value of orthophosphate plus MIC P_2O_5, 3.402 mg/l, was observed at Freeburg on Silver Creek, a tributary to the Kaskaskia River. However, the MIC phosphate in this sample was only 15 per cent.

Kaskaskia River Survey

A total of 125 stream samples were collected from the Kaskaskia River at seven different sampling stations from April to December 1956. The pertinent descriptive data and the average results for the seven stations are presented in Table I. It is noted that the mean value of MIC P_2O_5 is 0.200 mg/l, and that 50 per cent of the phosphate found is in the MIC form. Concentrations of orthophosphate in stream

TABLE V.—Summary of Orthophosphate Plus MIC Phosphate Concentrations for Kaskaskia River Survey, 1956*

P_2O_5 Range (mg/l)	Number of Samples in Range	Per Cent of Total Samples	Cumulative Per Cent
0 –0.1	17	13.6	13.6
0.1–0.2	26	20.8	34.4
0.2–0.3	23	18.4	52.8
0.3–0.4	19	15.2	68.0
0.4–0.5	9	7.2	75.2
0.5–0.6	12	9.6	84.8
0.6–0.7	3	2.4	87.2
0.7–0.8	2	1.6	88.8
0.8–0.9	2	1.6	90.4
0.9–1.0	4	3.2	93.6
1.0–1.1	3	2.4	96.0
1.1–1.2	1	0.8	96.8
1.2–1.3	0	0	96.8
1.3–1.4	1	0.8	97.6
1.4–1.5	0	0	97.6
1.5–1.6	0	0	97.6
1.6–1.7	1	0.8	98.4
1.7–1.8	0	0	98.4
1.8–1.9	0	0	98.4
1.9–2.0	0	0	98.4
2.0–3.0	1	0.8	99.2
3.0–4.0	0	0	99.2
4.0–4.27	1	0.8	100.0

* Total of 125 samples.

TABLE VI.—Mean Values and Ranges of Pounds Per Day of Orthophosphate and MIC P_2O_5 at Kaskaskia River Sampling Stations, 1956

Station	No. of Samples	P_2O_5 (lb/day)					
		Orthophosphate			MIC		
		Low	Mean	High	Low	Mean	High
Bondville	27	0.04	0.7	4.2	0.0	0.4	3.3
Above Ficklin	24	0.0	30.0	130.0	0.6	14.2	84.0
Below Ficklin	25	0.4	14.0	73.4	5.2	33.2	199.7
Shelbyville	25	1	911	12,810	0	1,749	36,030
Vandalia	10	21	611	5,167	8	1,858	17,223
Carlyle	7	34	486	1,838	25	477	1,694
New Athens	7	90	884	2,112	54	1,656	5,934

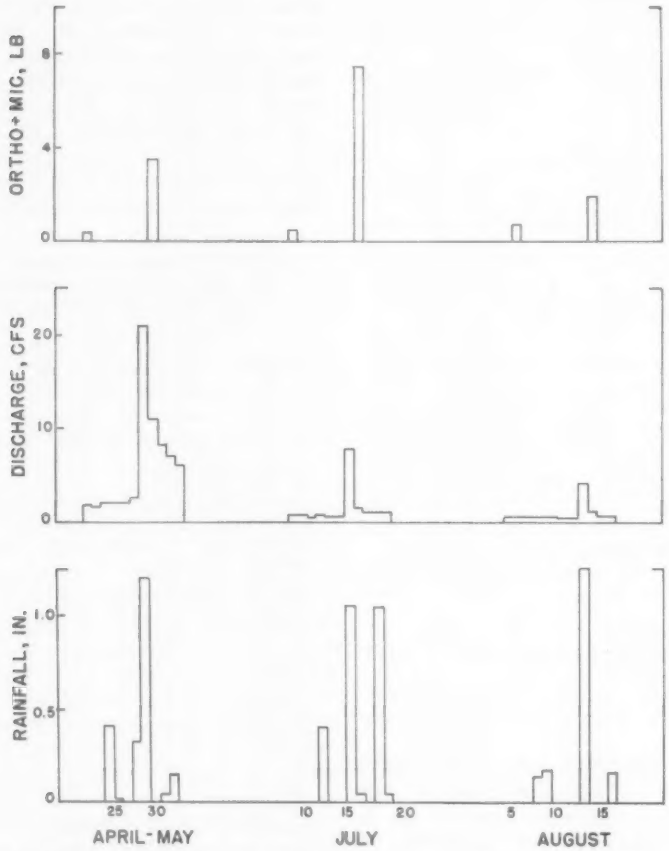

FIGURE 3.—Relation of rainfall and stream discharge to phosphates, Bondville.

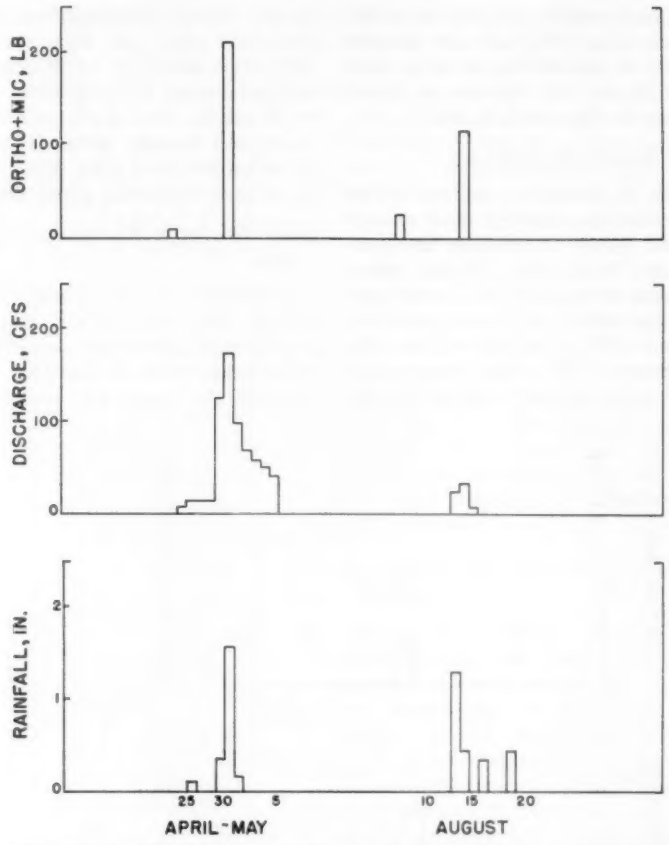

FIGURE 4.—Relation of rainfall and stream discharge to phosphates, Ficklin.

samples ranged from 0.01 mg/l to 1.76 mg/l P_2O_5. Concentrations of orthophosphate plus MIC P_2O_5 ranged from 0.03 to 4.27 mg/l. A summary of the frequency of occurrence of orthophosphate plus MIC P_2O_5 concentrations is presented in Table V. Ninety per cent of the samples are seen to have contained less than 0.9 mg/l P_2O_5 of orthophosphate plus MIC P_2O_5.

Phosphates in Kaskaskia River

Each Kaskaskia River sampling station was located near a U.S.G.S. stream gaging station. It was thus possible to compute the quantity of phosphate in the stream, corresponding to the observed concentration and the recorded daily stream discharge. The mean values and ranges of computed pounds per day of P_2O_5 for each Kaskaskia River station are presented in Table VI. The computed quantities of phosphates varied widely.

A study of records of rainfall and stream discharge in relation to date of sampling indicated that the quantity of orthophosphate plus MIC P_2O_5 generally increased with peak rainfalls and stream discharges. The observed relationships of rainfall, dis-

charge, and weight per day of orthophosphate plus MIC P_2O_5 for samples collected at Bondville, Ficklin, and Shelbyville on the Kaskaskia River are shown in Figures 3, 4, and 5.

Sewage Treatment Effluents

Results of phosphate analyses of 49 effluent samples collected at 4 sewage treatment plants in Illinois are presented in Table VII. Mean values and ranges of concentrations and per capita quantities of orthophosphate P_2O_5 and MIC P_2O_5 are shown for each effluent. The mean proportion of MIC P_2O_5 for each effluent is also shown. Mean concentrations of orthophosphate plus MIC P_2O_5 are seen to vary from about 12 to 26 mg/l, with extreme values ranging from about 5 to 40 mg/l. MIC P_2O_5 was observed to amount to only about 10 per cent of orthophosphate plus MIC P_2O_5 in the sewage treatment plant effluents.

Land Drainage Phosphate Contributions

Quantities of phosphate at each stream sampling station were computed, using phosphate concentrations and average daily discharges. By subtracting the upstream sewage phos-

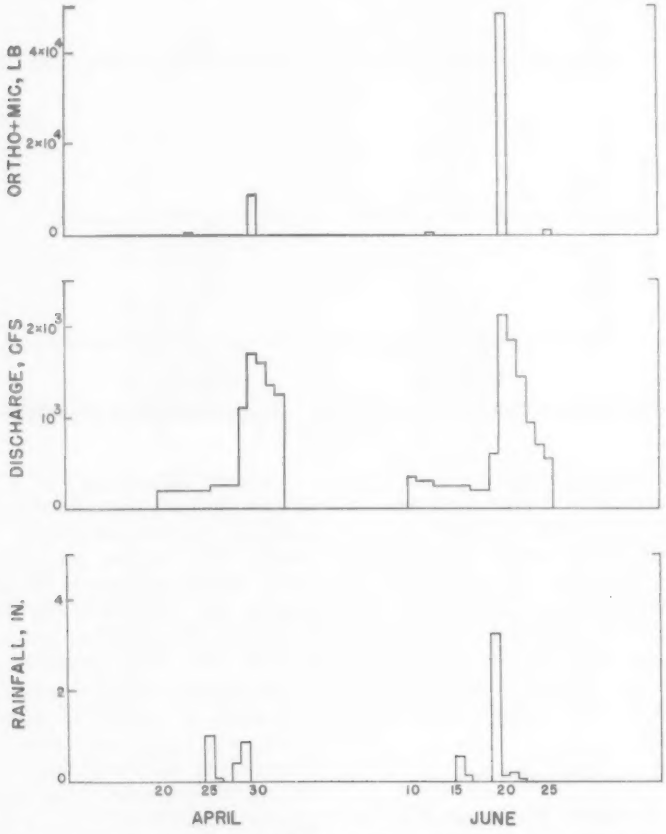

FIGURE 5.—Relation of rainfall and stream discharge to phosphates, Shelbyville.

TABLE VII.—Phosphate Content of Four Sewage Treatment Effluents in Illinois, 1956

Treatment Plant*	Population Served	No. of Samples	Orthophosphate P_2O_5						MIC P_2O_5						MIC P_2O_5 in Effluent (mean per cent)
			mg/l			10^{-3} lb/day/cap			mg/l			10^{-3} lb/day/cap			
			Low	Mean	High	Low	Mean	High	Low	Mean	High	Low	Mean	High	
Southwest Champaign	820	20	5.0	11.6	34.5	4.1	9.7	28.8	0.0	0.8	4.6	0.0	0.7	3.9	6.8
Arthur	1,600	12	4.7	14.8	24.9	2.9	9.4	16.4	0.4	2.1	5.6	0.3	1.3	3.0	11.9
Sullivan	3,400	10	16.6	24.2	36.00	13.2	24.2	40.0	0.0	2.1	3.5	0.0	2.25	3.6	8.5
Elmhurst	30,000	7	10.1	15.9	19.3	6.2	10.2	12.9	0.0	1.4	4.1	0.0	0.9	2.4	7.8

* All plants are standard rate trickling filter plants, with the exception of Elmhurst, which is an activated sludge plant.

phate quantities from the quantity observed at a given sampling station, an indirect estimate of land drainage phosphate contribution was determined. Calculations of amounts of phosphate attributed to drainage were made for each sample at each of six Kaskaskia River sampling stations. The average proportion of orthophosphate plus MIC P_2O_5 and the average weight per day of orthophosphate plus MIC P_2O_5 per square mile of cultivated drainage for each station are presented in Table VIII. The range of values is also indicated. The over-all mean orthophosphate plus MIC P_2O_5 from land drainage was 45 per cent. The over-all mean contribution of orthophosphate plus MIC P_2O_5 from land drainage was 1.40 lb/day/sq mile.

Degradation Studies—Various Surface Waters

Pertinent chemical and physical characteristics were determined for all the natural waters used in studying the degradation of condensed phosphate. It was found that the total hardness of these waters varied from 170 to 1,050 mg/l, calcium hardness from 55 to 893 mg/l, and the total alkalinity from 110 to 298 mg/l, all expressed as $CaCO_3$; turbidity ranged from 0 to 98 mg/l. The lowest pH value was observed to be 7.3, while the highest was 8.6. Except for the Kincaid, Mattoon, and Springfield samples, all of the waters were found to contain some phosphate (Table III). The orthophosphate concentration varied from 0.00 to 0.92 mg/l P_2O_5 and the condensed phosphate from 0.00 to 0.31 mg/l P_2O_5.

The results for the general surface water storage studies, expressed as half life values, are presented in Table IX. Included in this table is the source of water, storage condition, condensed phosphate used and the amount added, and the pretreatment methods employed for the filtered quiescent,

TABLE VIII.—Estimates of Stream Phosphates Contributed by Land Drainage, Kaskaskia River, 1956

Station	Cultivated Sq Miles	Orthophosphate Plus MIC P_2O_5 from Drainage (per cent)			Orthophosphate Plus MIC P_2O_5 from Drainage (lb/day/sq mile)		
		Low	Mean	High	Low	Mean	High
Bondville	10.6	—	100	—	0.01	0.10	0.71
Above Ficklin	109	11	55	92	0.01	0.18	1.89
Shelbyville	842	2	43	99.6	0.00	3.04	57.80
Vandalia	1,505	6	23	99	0.01	1.56	14.77
Carlyle	1,850	36	54	93	0.07	0.40	1.78
New Athens	4,020	1	33	88	0.00	0.37	1.76
Over-all Mean	—	—	45	—	—	1.40	—

filtered semi-quiescent, and filtered turbulent samples. Representative data, using the Mattoon storage experiment, are shown in Figure 6.

From these data, it is apparent that the rate of degradation of STP varied in the different surface waters. In considering the various chemical and physical characteristics of the different raw waters before pretreatment and the addition of STP, there appeared to be no correlation of rate of degradation with turbidity, total and calcium hardness, or alkalinity. However, there was an indication that half life decreased with increasing amounts of the MIC P_2O_5 originally present in the raw water sample.

Although a change in total hardness and/or pH was noted in several of the stored samples, no conclusions were drawn.

A significant observation to be made concerning the results presented in Table IX is the general difference in the rate of degradation between the filtered and nonfiltered samples. With the exception of the storage experiments made with Danville water, the filtered samples consistently degraded STP more slowly than the nonfiltered samples. In addition to removing suspended solids, the filtering methods employed reduced the bacterial population in the water. This was confirmed by bacterial plate counts made before and after filtration and by a comparison of counts made on both the filtered and nonfiltered storage samples. These observations definitely indicated that biological life accelerated the rate of degradation of STP.

Table IX also shows that the rate of degradation was, in general, less in the turbulent samples than in the corresponding quiescent and semi-quiescent samples. In considering all of the available data, including the results of dissolved oxygen measurements made during storage, there was no readily apparent reason for this observation.

To compare the rate of degradation of STP and TSPP, three separate studies were made using New Athens water. In considering each storage run separately, a comparison of the corresponding nonfiltered semi-quiescent and nonfiltered turbulent samples containing added STP and TSPP, respectively, indicated that TSPP degraded more slowly than STP in all but one case, the nonfiltered turbulent samples of Experiment No. 9 (Table IX). However, since the half life values were all relatively short, especially those given in Experiment Nos. 7 and 9, caution should be exercised in evaluating these data. The larger magnitude of difference between the STP and TSPP samples of Experiment No. 8 was probably due to the combined effect of different compounds and concentrations.

TABLE IX.—General Storage Studies of Various Illinois Surface Waters

Experiment No.	Storage Source	Storage Condition*	Phosphorus Compound Added	Phosphorus Added as P_2O_5 (mg/l)	Half Life (days)	Pretreatment Conditions
1	Mattoon—Little Wabash River (Reservoir)	NFQ	STP	9.16	11.0	Filtered through paper and membrane filter
		NFSQ	STP	9.16	14.5	
		NFT	STP	9.16	19.5	
		FQ	STP	9.16	31.5	
		FSQ	STP	9.16	37.0	
		FT	STP	9.16	45.0	
2	Bloomington—Money Creek (Reservoir)	NFQ	STP	2.2	6.0	Filtered through cotton and paper
		NFSQ	STP	2.2	7.0	
		NFT	STP	2.2	8.0	
		FQ	STP	2.2	27.0	
		FSQ	STP	2.2	17.0	
		FT	STP	2.2	34.0	
3	Kincaid—Tributary of Sangamon River (Reservoir)	NFQ	STP	2.2	13.5	Filtered through cotton and paper
		NFSQ	STP	2.2	13.9	
		NFT	STP	2.2	15.0	
		FQ	STP	2.2	24.6	
		FSQ	STP	2.2	25.0	
		FT	STP	2.2	26.0	
4	Springfield—Sugar Creek (Reservoir)	NFQ	STP	2.2	28.5	Filtered through cotton, paper, and membrane filter
		NFSQ	STP	2.2	26.0	
		NFT	STP	2.2	29.9	
		FQ	STP	2.2	33.5	
		FSQ	STP	2.2	72.0	
		FT	STP	2.2	36.0	
5	Danville—N. Fork Vermilion River (Reservoir)	NFQ	STP	2.2	4.2	Filtered through cotton, paper, and membrane filter
		NFSQ	STP	2.2	14.0	
		NFT	STP	2.2	17.0	
		FQ	STP	2.2	1.0	
		FSQ	STP	2.2	1.9	
		FT	STP	2.2	13.3	
6	Danville	NFQ	STP	2.2	6.5	Filtered through paper and membrane filter
		NFSQ	STP	2.2	7.3	
		NFT	STP	2.2	10.0	
		FQ	STP	2.2	8.0	
		FSQ	STP	2.2	14.0	
		FT	STP	2.2	3.0	
7	New Athens—Kaskaskia River	NFSQ	STP	2.2	2.4	—
		NFT	STP	2.2	3.0	
		NFSQ	TSPP	2.2	2.5	
		NFT	TSPP	2.2	3.6	
8	New Athens	NFSQ	STP	2.2	2.2	—
		NFT	STP	2.2	2.1	
		NFSQ	TSPP	5.5	7.5	
		NFT	TSPP	5.5	5.4	
9	New Athens	NFSQ	STP	2.2	0.4	—
		NFT	STP	2.2	0.6	
		NFSQ	TSPP	2.2	1.0	
		NFT	TSPP	2.2	0.5	

* NFQ = Nonfiltered quiescent, NFSQ = Nonfiltered semi-quiescent, NFT = Nonfiltered turbulent, FQ = Filtered quiescent, FSQ = Filtered semi-quiescent, and FT = Filtered turbulent.

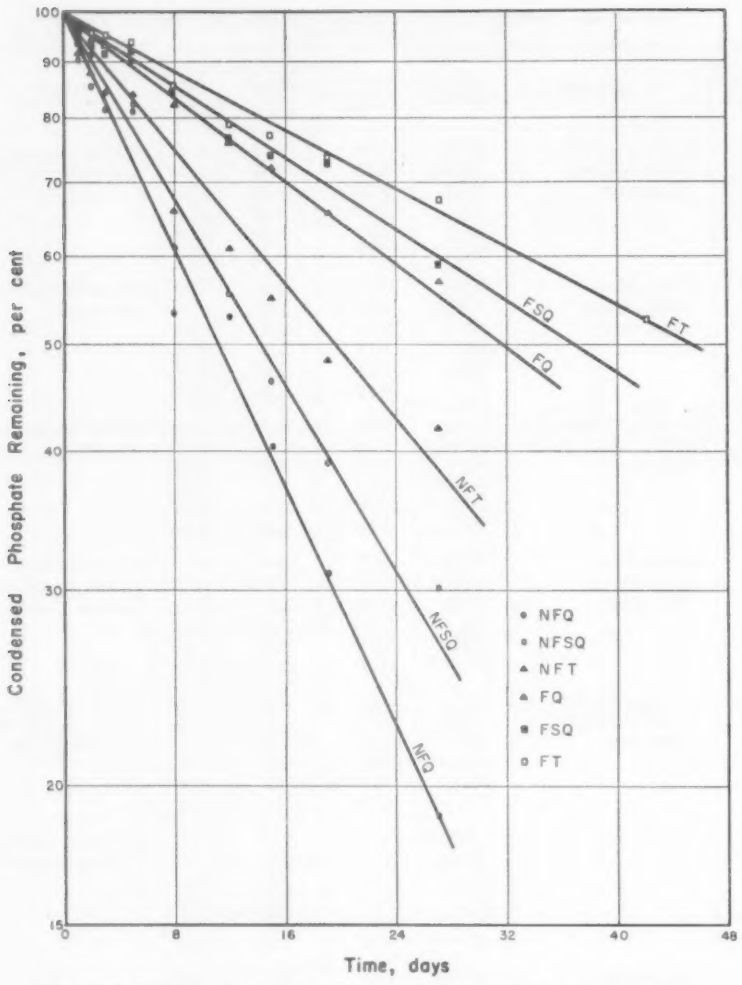

FIGURE 6.—Degradation of 9.16 mg/l (P_2O_5) STP in Mattoon water.

Degradation Studies—Kaskaskia River

Table X gives the results of the more extensive storage studies made using waters collected at various locations along the Kaskaskia River. The mile points for the various sampling locations, with reference to Bondville, are shown in Table I. In these studies, STP was added to all of the samples in order to give a concentration of 3.0 mg/l P_2O_5, and all samples were stored under nonfiltered, turbulent conditions. From these results (Table X), it is quite evident that there is wide variation in half values for the waters collected at different locations on any given date. It is also quite apparent that the rate of degradation of STP varies in samples collected at the same location but at different times.

TABLE X.—Half Life Values for the Kaskaskia River Storage Studies Using STP at a Concentration of 3.0 mg/l P_2O_5 Under Nonfiltered Turbulent Condition

Experiment No.	Collection Date (1956)	Half Life (days)						
		Bondville	Ficklin A	Ficklin B	Shelbyville	Vandalia	Carlyle	New Athens
10	9/20	13.3	3.0	—	—	—	—	—
11	10/8	—	11.0	—	7.4	—	—	—
12	10/15	—	—	—	8.0	3.1	—	—
13	10/29	10.0	14.0	0.4	9.0	5.5	8.0	8.0
14	11/12	27.5	18.5	0.8	8.5	9.5	—	—
15	12/3	32.0	26.0	1.0	24.0	6.0	—	—

In initiating several of these studies, bacterial plate counts were made on the raw waters before the addition of STP. The results showed that the Ficklin B sample generally gave the highest total bacterial count. This probably accounted for the consistently greater rate of degradation in this sample when compared to the other samples collected at any one time.

Degradation Studies—Half Life and COD

Because of organic pollution above the Ficklin B station, Chemical Oxygen Demand measurement was made on the raw water samples used in Experiment No. 13. These results are given in Table XI. Except for the Shelbyville sample, there is an indicated correlation between half life and COD.

Degradation Studies—Further Tests

Another series of experiments was carried out using Kaskaskia River water collected at Ficklin A. In one experiment, a single sample of water was divided into six portions. Before being stored under nonfiltered turbulent conditions, 3.0 mg/l P_2O_5 of STP was added to each portion. The mean half life was found to be 29 days with a standard deviation of 21 per cent. A similar experiment was made with TSPP, but used a different sample of water. An analysis of the results gave a mean half life of 14 days and a standard deviation of 8 per cent. Although these two experiments indicated that STP degraded more slowly than TSPP in water from the same location, the two studies cannot be directly compared because the waters were collected at different times.

A comparison of the rate of degradation of 3.0 mg/l P_2O_5 of STP and TSPP in individual portions of a Ficklin A water sample, under nonfiltered turbulent conditions, is shown in Figure 7. Six separate portions of the same sample of water, three containing STP and three containing TSPP, were stored. The mean half life value for the three STP storage samples was 25 days while that of the TSPP samples was 38 days. Therefore, these values and the data presented in Figure 7 show that TSPP has greater stability, or a slower rate of degradation, than STP. These results agree with the observations made using New Athens waters and reported

TABLE XI.—Half Life and COD Values for Kaskaskia River Samples Collected October 29, 1956 (Table X, Exper. No. 13)

Location	Half Life (days)	COD (mg/l)
Ficklin B	0.4	87.6
Shelbyville	9.0	55.8
Vandalia	5.5	31.9
New Athens	8.0	31.9
Carlyle	8.0	23.9
Bondville	10.0	23.9
Ficklin A	14.0	12.0

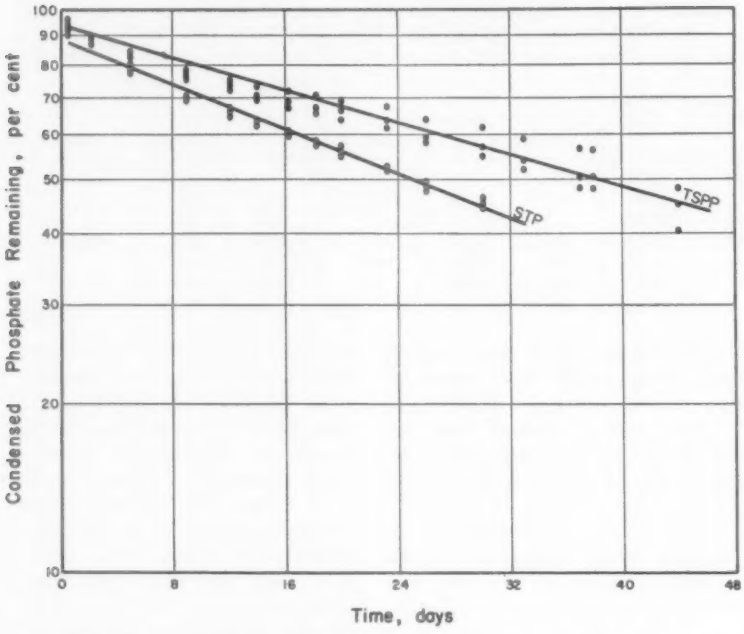

FIGURE 7.—Degradation of three portions each of STP and TSPP in the same Ficklin A water sample—3 mg/l (P_2O_5).

in Table IX. Thus, it can be concluded that, when the same natural water sample, considering both the source and time of collection, is used for storage, STP degrades at a greater rate than TSPP.

Discussion

Condensed P_2O_5

The data of Table II indicate the presence of organic P_2O_5 in streams. Since the acid hydrolysis step in the P_2O_5 determination is known to pick up a portion of condensed organic phosphate, it is reasonable to conclude that the condensed P_2O_5 determined by this method is likely to be greater than the true value of condensed inorganic P_2O_5. Thus, the results reported as condensed P_2O_5 are interpreted as being equal to or greater than the true condensed inorganic P_2O_5, and have been referred to as maximum inorganic condensed P_2O_5 (MIC).

P_2O_5 in Surface Waters and Sewage

Results of the surveys of Illinois surface water supply sources in general indicate rather low levels of P_2O_5. Lake and reservoir sources, as expected, showed less than 0.1 mg/l orthophosphate plus MIC P_2O_5, on the average. Stream sources which received treated and untreated wastes averaged less than 1.0 mg/l P_2O_5. The highest values were generally observed in rivers such as the Mississippi and Illinois, which received wastes from large upstream populations. Results of an intensive survey of the Kaskaskia River, involving 125 samples, showed an average orthophosphate plus MIC P_2O_5 content of 0.4 mg/l. As indicated in Table V, 90 per cent of all samples contained less than 0.9 mg/l P_2O_5. For the Kaskaskia River at

New Athens, where the tributary population upstream was 90,000, the average MIC P_2O_5 was 0.230 mg/l. It is interesting to note that the average per cent MIC P_2O_5 in all Kaskaskia stream samples was 50 per cent of the orthophosphate plus MIC P_2O_5 while that for three sewage treatment plant effluents in the Kaskaskia basin was 10 per cent. A possible explanation of this difference in the relative proportions of MIC P_2O_5 in sewage and stream samples is provided by evidence that appreciable quantities of stream P_2O_5 are of land drainage origin. The extreme variability in the quantities of stream P_2O_5 presented in Table VI suggests a phosphate source other than waste effluents. This observation is confirmed by the data in Figures 3, 4, and 5, showing marked increases in pounds of P_2O_5, corresponding to peaks of rainfall and stream discharge. The stream sampling results for Bondville, which receives no significant domestic wastes, showed an average orthophosphate plus MIC P_2O_5 content of 0.163 mg/l, of which 30 per cent was found to be in the MIC form. Silvey (4) described a process whereby organic plant phosphates from fertilizers could be washed to streams, and these results tend to agree with his discussion.

Sewage effluent results indicate that approximately 90 per cent of the P_2O_5 present in effluents is already in the orthophosphate form. Mean per capita values of effluent orthophosphate plus MIC P_2O_5 in Table VII ranged from 11×10^{-3} to 26×10^{-3} lb/day. Estimates of average synthetic detergent consumption in the U. S. during 1955 indicated that approximately 12×10^{-3} lb/day/cap P_2O_5 would be expected in raw sewage because of synthetic detergent contributions. Rudolfs (1) reported removals of P_2O_5 in sewage treatment of from 50 to 80 per cent.

Estimates of Kaskaskia basin land drainage P_2O_5 based on sewage effluent and stream data indicated appreciable fluctuation. However, the over-all mean value of orthophosphate plus MIC P_2O_5 from land drainage was 1.40 lb/day/sq mile. This is in agreement with the results of Sawyer (3). Sawyer reported 255 pounds of phosphorus per year per square mile for the Madison, Wisconsin, area, which in terms of P_2O_5, amounts to 1.6 lb/day/sq mile.

An over-all consideration of the 1955–56 data presented in this study leads to the general conclusion that concentrations of MIC P_2O_5 in Illinois surface waters were generally less than 0.5 mg/l, and those of orthophosphate plus MIC P_2O_5 were generally less than 1.0 mg/l. Approximately 45 per cent of stream orthophosphate plus MIC P_2O_5, on the average, was attributed to land drainage. MIC P_2O_5 in sewage treatment plant effluent amounted to only 10 per cent, or roughly 1×10^{-3} to 2×10^{-3} lb P_2O_5/day/cap.

In relating the results of this study of the P_2O_5 content of Illinois surface waters and sewage effluents during 1955–56 to possible results for other areas, certain factors are to be borne in mind: (a) Illinois is in a hard water region, and, therefore, consumption of synthetic detergents would be expected to be higher than in many other areas; (b) rainfall and stream runoff in Illinois during 1955–56 were generally low in relation to the long-term average and, therefore, the available stream flow dilution for synthetic detergent phosphates was low in relation to what might be expected as an average; and (c) a considerable portion of the P_2O_5 found in Illinois streams is undoubtedly of land drainage origin. Topography, agricultural practices, and rainfall distribution will vary in different areas, thus affecting the concentrations of stream P_2O_5.

Degradation

Because of the inherent peptizing and dispersing properties of condensed

phosphates, it is logical to suspect that these compounds could interfere with coagulation and sedimentation processes in the treatment of water supplies. Knowing that these condensed phosphates could pass through sewage treatment plants into receiving streams, their persistence or degradation in natural waters becomes important. This might be particularly important where a community uses a raw water supply which upstream receives an effluent from a sewage treatment plant. Therefore, the objective of this phase of the investigation was to determine whether condensed phosphates underwent degradation in natural water to form orthophosphate and, if they did, to study the conditions which affect this degradation.

It has been definitely established that degradation of condensed phosphates, as represented by STP and TSPP, does occur in natural waters. This has been shown in this study, as well as the studies by Smith, Cohen, and Walton (9).

Where experimental conditions were essentially the same, it was apparent that natural waters, collected at different locations, degraded the condensed phosphates, STP and TSPP, at different rates. Although the chemical and physical composition of the natural waters differed, there was no distinct correlation between rate of degradation and these various characteristics. Considering the inorganic chemical characteristics determined, the only possible exception was with the MIC phosphate concentration originally present. Natural raw waters which had a significant amount of MIC phosphate present generally gave the shortest half life when condensed phosphate was added. Furthermore, there was an indication that half life decreased as the MIC phosphate concentration present in the natural raw water increased.

Except for the studies made with Danville water, it was quite apparent that filtration decreased the rate of degradation. It was found that all of the filtration methods employed reduced the concentration of suspended solids, including the various forms of biological life, originally present in the natural waters. Furthermore, it has been shown that the membrane filter technique effectively removes all organisms, producing a sterile filtrate.

A series of studies, using waters collected at various sampling stations along the Kaskaskia River, showed that the rate of degradation of STP varied in the different samples even though they were all obtained on the same date. It was also found that the stability of STP differed in waters collected at the same station, but at different times. The greatest rate of degradation of STP was observed in the Ficklin B sample regardless of time of collection. Through the use of bacterial plate counts, it was found that the raw water from this sampling station consistently gave the highest count.

Considering this same series of studies, COD measurements were made on all the raw water samples collected at the different stations on one particular day. Of the eight samples collected and stored, there was only one exception to the observation that the rate of degradation of STP decreased as the amount of COD in the raw water decreased. Thus, there was an indicated correlation between organic matter in the raw water and half life. Furthermore, the greatest amount of COD was found in the Ficklin B sample. This fact could well be related to the greater amount of biological life observed in this source of water, which in turn might account for the accelerated rate of degradation of STP.

In summary, it appeared that biological life, through enzymatic activity, definitely influences the degradation of condensed phosphate and the rate at which it occurs. This observa-

tion is in agreement with the conclusions reported by Karl-Kroupa *et al.* (8).

It was found that STP degraded at a more rapid rate than TSPP when the same sample of natural water was used. If two water samples from the same source, but collected at different times, were used to determine the rate of degradation, it was possible to observe that TSPP degraded faster in one sample than did STP in the other. This indicated that the chemical, physical, and/or biological properties of natural water can influence degradation of condensed phosphate. Since these properties are subject to change in natural waters, only when the same sample is used can the rate of STP and TSPP be compared. Smith *et al.* (9) also found that STP generally degraded faster than TSPP. However, this observation was made on separate samples of Ohio River water and, therefore, cannot be compared directly. Working with domestic sewage, Sawyer (2) found that STP degraded much more slowly than TSPP. This was in contrast to the findings in this study.

Summary

The results of these studies on the occurrence and degradation of condensed phosphate in surface waters indicated the following:

1. Maximum inorganic condensed (MIC) P_2O_5 in Illinois surface water supplies was generally less than 0.5 mg/l, and orthophosphate plus MIC P_2O_5 was generally less than 1.0 mg/l.

2. The Kaskaskia River, having a total drainage area of 5,670 sq miles and a tributary sewered population of 90,000, showed a mean MIC P_2O_5 of 0.20 mg/l. MIC P_2O_5 was found to be less than 0.50 mg/l in 90 per cent of the samples collected.

3. Per capita values of MIC P_2O_5 in four sewage treatment plant effluents averaged from 1×10^{-3} to 2×10^{-3} lb/day. MIC P_2O_5 amounted to 10 per cent of the orthophosphate plus MIC P_2O_5 in treated sewage effluents. Average values of orthophosphate plus MIC P_2O_5 in treated effluents were from 11×10^{-3} to 26×10^{-3} lb/day/cap.

4. Approximately 45 per cent, on the average, of the orthophosphate plus MIC P_2O_5 found in Kaskaskia River stream samples was of land drainage origin. The over-all mean land drainage orthophosphate plus MIC P_2O_5 was found to amount to 1.40 lb/day/sq mile of cultivated drainage.

5. Condensed phosphates, as represented by STP and TSPP, were subject to hydrolytic degradation in natural waters. The rate of degradation varied in different natural waters, having different chemical and physical characteristics. With the possible exception of the concentration of organic matter and MIC phosphate in the natural raw water, both of which appeared to increase the rate of degradation, there seemed to be no correlation between rate and these characteristics.

6. Natural waters, collected at the same time but at different locations along a single river, gave different rates of degradation. Similarly, the rate of degradation varied in natural waters, collected at different times but at the same location.

7. Filtration of the raw water definitely decreased the rate of degradation. This result, supported by bacteriological data, indicated that biological life exerted an effect on the rate of degradation.

8. Of the condensed phosphates studied, STP degraded more rapidly than TSPP when the same natural water was used for study. However, if the degradation of STP and TSPP was studied separately, using either different natural waters or different samples of the same water, TSPP could be observed to degrade faster than STP.

Acknowledgments

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"THE WORST PUBLIC-WORKS PROBLEM" AVAILABLE

Through the courtesy of the Water and Sewage Works Manufacturers Association, the Federation has for distribution a number of reprints of an article from the December 1958 issue of FORTUNE entitled, "The Worst Public-Works Problem," by Edward T. Thompson.

In this interesting article the author gives the reasons why he believes that the lack of water and wastewater facilities constitutes the greatest single deficiency in United States public works, and what he feels the future prospects are for solution of the problem.

Anyone interested in a copy of this five-page reprint may receive it on request from the Federation office as long as the supply lasts.

THE OPERATOR'S CORNER

JOB CLASSIFICATIONS AND SALARY SCALES FOR WATER AND SEWAGE TREATMENT PLANT OPERATORS *

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When the Operator Salary Study Committee of the Florida Water and Sewage Works Operators Association learned that jobs were being studied at selected sewage treatment plants in Florida it requested that the study be expanded to determine the relative value of jobs in both water and sewage treatment plants, and to establish minimum and maximum salaries for these jobs. As a result, a job evaluation study was conducted at nine sewage and three water treatment plants of various types and sizes.

Job evaluation is the systematic ranking or grading of jobs to determine their labor worth. In this study the point-rating method of evaluation was used. The procedure for this method is given below.

Point-Rating Method

Job Characteristics

Fundamentally, the point-rating method permits the comparison of the characteristics of a particular job with a set of standards or definitions. Points are awarded in proportion to the degree to which these characteristics are present in the job being evaluated.

As a first step, all jobs to be evaluated must be studied to determine the characteristics and factors to be used in measuring job worth. The characteristics and factors used in the Florida study are shown in Table I.

As a second step, the maximum and minimum degree of presence of each factor is set so that all jobs to be evaluated will fall within the degrees selected. Next, a point value is assigned to each degree to establish the "basis of rating." The basis of rating

TABLE I.—Characteristics and Factors Considered

Characteristics	Factors
Skill	Education, experience, ability
Effort	Physical demand, mental or visual demand
Responsibility	Equipment, material, safety of others, work of others
Job conditions	Working conditions, hazards

* Presented at the 9th Joint Conference, Florida Section, American Water Works Assn. and Florida Sewage and Industrial Wastes Assn.; Oct. 19–22, 1958; Miami Beach, Fla.

TABLE II.—Basis of Rating

Factor	Degree	Point-Rating
Education	Four years' college.	140
	Working knowledge of algebra and trigonometry. Write technical reports. Equivalent of 2 years' college or graduate of technical institute.	120
	Advanced shop arithmetic. Make or read fairly complicated drawings. Assist on technical reports. Equivalent of high school graduate.	112
	Write simple reports. Make or read simple reports. Handle fractions, simple graphs, and formulas. Equivalent of 2 years' high school.	84
	Read and write readily. Handle simple arithmetic. Equivalent of grade school graduate.	56
	Minimum ability to read and write. Add and subtract simple numbers.	28
	No education required.	0
Experience	4 years or more.	220
	2 to 4 years.	176
	1 to 2 years.	132
	3 months to 1 year.	88
	1 week to 3 months.	44
	Less than 1 week.	22
Ability	Requires outstanding ability to achieve successful results on complex jobs.	140
	Requires superior ability to achieve successful results on jobs which are somewhat complex.	112
	Requires ability to plan and perform a sequence of operations where recognized operation methods are available.	84
	Requires ability to work from detailed instructions and the making of minor decisions.	56
	Requires little or no ability because employee is expected to follow simple instructions.	28
Physical demand	Continuous, heavy physical effort or intermittent with severe strain.	100
	Considerable physical effort or continuous strain of difficult work position.	80
	Continuous physical activity but with light- or average-weight materials.	60
	Light physical effort with light-weight materials. In servicing machines, handling time requires only part of cycle time.	40
	Very light work requiring little physical effort.	20
Mental or visual demand	Highly concentrated mental or visual attention on very complex jobs.	50
	Must concentrate mental or visual attention closely on complex jobs or manual dexterity with close visual attention for sustained periods.	40
Mental or visual demand —*Continued*	Continuous mental or visual attention on repetitive work requiring constant alertness.	30
	Frequent mental or visual attention, intermittent work flow. Machine needs little attention.	20
	Little mental and only intermittent visual attention. Operation practically automatic requiring attention only after long intervals.	10
Equipment or material	Possible loss by employee very high (to $2,000).	50
	Possible loss by employee high (to $500).	40
	Possible loss by employee limited (to $250).	30
	Possible loss by employee low (to $100).	20
	Possibility of loss or damage slight ($10.00 or less).	10
Safety of others	Heavy responsibility for health and safety of many others.	50
	Heavy responsibility for health and safety of few others.	40
	Carelessness may cause injury to another.	30
	Not much chance for injury to another.	20
	Practically no chance for injury to another.	10
Work of others	Acts as group leader of 8 to 15 employees in addition to own duties.	50
	Acts as group leader of 6 to 10 employees in addition to own duties.	40
	Responsible for follow-up, assignment, checking work of 3 to 6 employees.	30
	Responsible for instructing new or inexperienced employees in own work or other functions as may be specified. May also be required to check work of 1 or 2 others.	20
	No responsibility except to pass on to others information gained through experience on the job.	10
Working conditions	Very dirty, hot, or uncomfortable.	100
	Quite dirty, hot, or uncomfortable.	80
	Disagreeable.	60
	Good. Slightly dirty or occasional exposure to dust, dirt, heat, fumes, noise, vibration, wet.	40
	Approaching ideal conditions.	20
Hazards	Dangerous work. Exposure to serious accident hazards or occupational disease.	50
	Somewhat dangerous work. Considerable exposure to accident hazards or occupational disease.	40
	Reasonably safe but some exposure to accident hazards or occupational disease.	30
	Safe. Accidents improbable.	20
	Accident or health hazards negligible.	10

used in this study is the same as that used by the University of Florida for rating semi-skilled and technical jobs. It is shown in Table II.

Point-Rating the Jobs

First, the plants must be visited and the jobs studied to determine the job requirements. To complete the picture

JOB RATING
SUMMARY OF POINTS

Date 5-28-58

"I" STP AVERAGE FLOW 0.8 MGD

Factors \ Job Title	Laborer	Operator	Chief Operator	Superintendent
Education	56	84	84	112
Experience	22	88	176	132
Ability	28	56	56	84
Physical Demand	40	40	40	40
Mental Demand	10	30	30	30
Equipment	10	20	20	30
Material	10	20	10	20
Safety of Others	20	20	30	30
Work of Others	10	10	30	40
Working Conditions	40	40	40	40
Hazards	30	30	30	30
TOTAL POINTS	290	438	546	588
AVERAGE SALARY	$318	$350	$347	$347

FIGURE 1.—Summary form used for data recording.

the job requirements should be discussed with the man and the superintendent. Based on the job descriptions, observations, and discussions, points are assigned to each job for each factor.

In this connection it may be found helpful to record the points for each job on a summary sheet. A summary of data from a job evaluation study at a sewage treatment plant is shown in Figure 1.

The job-point totals and corresponding salaries for 55 jobs at 12 treatment plants are shown in Table III.

Job Points—Salary Relationship

To find the relationship between job points and salaries the data are plotted on graph paper. Job-point totals are plotted along the X axis and the corresponding salaries are plotted along the Y axis. The resulting plot is called a scatter diagram. Figure 2 is a scatter diagram that was developed from the data in Table III.

A curve can be fitted to the plotted data by the graphical method, *i.e.*, the line of best fit is drawn by eye, or by the method of least squares (1). The The latter method is preferred by many authorities. The least squares line for the data in Figure 1 is shown in Figure 3.

Job Levels

In the Florida study no more than six salary levels were found at any one plant. Since the point-rating for the lowest job was 260 and for the

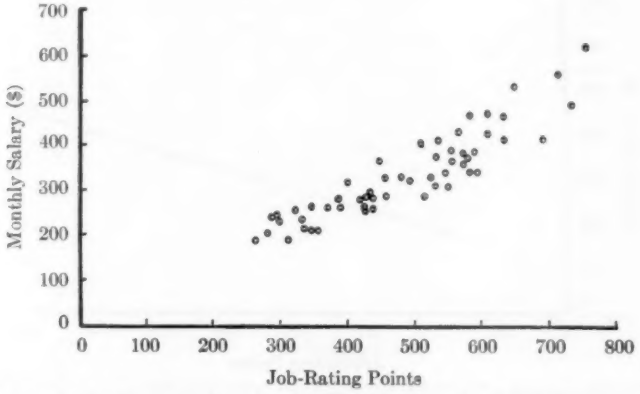

FIGURE 2.—Scatter diagram plotted from data collected at nine sewage and three water treatment plants.

TABLE III.—Point-Ratings and Monthly Salaries at 12 Treatment Plants

Plant	Point-Rating	Monthly Salary	Plant	Point-Rating	Monthly Salary
A	334	$290	G	334	$230
	448	323		428	282
	552	368			
	510	410	H	308	192
	604	475		346	208
				384	258
B	260	195		456	292
	424	282		570	362
	512	292		628	467
	550	314			
			I	296	238
C	278	208		438	287
	438	298		546	347
	578	477		588	347
	648	540			
			J	528	383
D	338	217		458	333
	424	260		578	383
	438	260		296	243
	532	314			
	570	390	K	318	254
				416	279
E	356	210		488	329
	386	288		522	340
	478	340		580	394
	634	417		734	498
	534	417			
	690	417	L	280	248
	760	622		368	260
				556	398
F	346	260		448	372
	578	350		610	431
				712	559

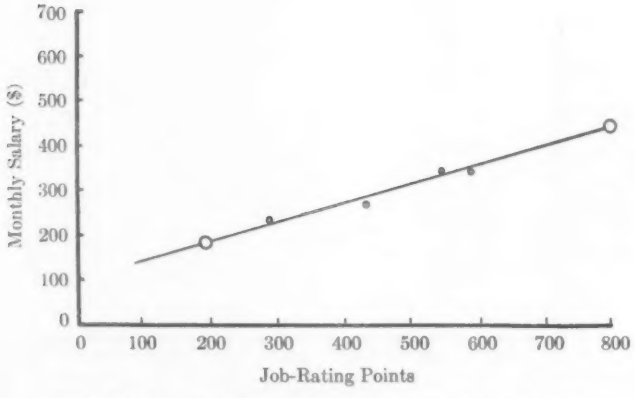

FIGURE 3.—Least squares line for data shown in Figure 1.

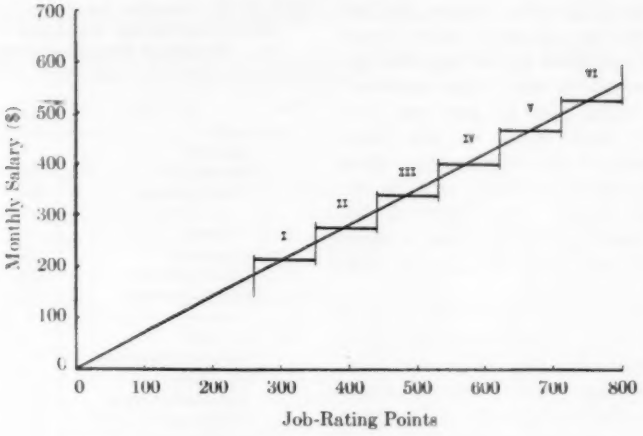

FIGURE 4.—Job levels at 12 treatment plants in Florida.

highest job, 760, it was reasoned that the range of points for the six job levels could be from 260 to 800 points or 90 points per job level. These job levels are shown in Figure 4.

In analyzing the data from any plant the number of points between successive job levels may be computed by dividing the total range of points by the number of job levels necessary.

Salary Ranges

Salary ranges must be determined in a manner that will benefit all job levels equally. This means that before an orderly salary schedule can be established extreme variations in the data must be resolved. This is largely an exercise in administrative judgment.

Based on six job levels in Florida,

FIGURE 5.—Upper and lower salary limits established for 12 treatment plants in Florida.

each with a 90-point range, it was decided that an adequate salary range would be provided by setting the upper limit equal to the "least squares" or curve value plus 15 per cent, and the lower limit equal to this same value minus 15 per cent. Also, these limits provide for salary overlap between job levels. In Figure 5 the salary limit and least squares lines have been added to the scatter diagram.

Some of the individual salary plots in Figure 5 are outside the limit lines. For those values below the lower limit, salary increases seem to be in order. It does not follow, however, that salary cuts should be instituted for jobs paying more than the upper limit. There would seem to be little wisdom in introducing discord when the elimination of dissatisfaction is a major objective of a job evaluation study. At any rate, the apparent unfairness of an "overpaid" job can be eliminated by increasing the duties or responsibilities associated with that particular position.

Conclusions

The results of a job evaluation study may make possible and feasible the establishment of salary ranges for specific jobs at treatment plants of various sizes and types. For example, some of the results of the Florida study have been arranged to form a table which indicates job titles, job levels, and corresponding salary ranges for treatment plant operators (Table IV). The plants listed in Table IV are of various sizes and types, thus the number of job levels at each of the plants is variable. The job levels are numbered from I, the lowest, to VI, the highest.

A table similar to Table IV may be used to answer inquiries concerning salaries of personnel for new or proposed plants.

From past experience it is believed that state-wide job evaluation studies should be performed by a small committee. The combined interests of the committeemen should cover the range of operational activities. The committee would decide on the factors to be considered in rating a job, as well as the definitions and the point values to be assigned.

Inasmuch as the study reported herein was conducted by an individual, the results are intended to be used only as a guide in making future studies under an evaluation committee.

Once a job evaluation system is established a permanent committee should be maintained to review and compare job descriptions, point-ratings, job levels, and salaries in the light of changing conditions.

TABLE IV.—Possible Job Titles, Levels, and Salaries for Florida Water and Sewage Treatment Plant Employees

Plant	Job Title	Job Level	Monthly Salary
1	Laborer	I	$182–246
	Operator	II	235–318
	Chief operator	III	288–390
2	Laborer	I	182–246
	Operator	II	235–318
	Chief operator	III	288–390
	Superintendent	IV	341–462
3	Laborer	I	182–246
	Assistant operator	II	235–318
	Operator	III	288–390
	Operator-chemist	III	288–390
	Maintenance chief	IV	341–462
	Chief operator	IV	341–462
	Superintendent	V	394–534
4	Laborer	I	182–246
	Sludge tank operator	II	235–318
	Plant operator	III	288–390
	Chemist	IV	341–462
	Maintenance chief	V	394–534
	Chief operator	V	394–534
	Superintendent	VI	448–606

Reference

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PLANT MAINTENANCE—PANEL DISCUSSION *

I. SLUDGE PIPE CLEANING AT MINNEAPOLIS–SAINT PAUL, MINNESOTA

By John C. Sager †

Engineer of Maintenance and Design, Minneapolis—Saint Paul Sanitary District, Minneapolis, Minn.

The Problem

The Minneapolis—Saint Paul treatment plant began operations during June 1938. Ten years later, a buildup started to form in the two 8-in. raw sludge lines which connect the sludge pumps to the concentration tanks and in the two 6-in. lines which connect the concentration tanks to the bucket elevators.

The grease content of dry weather raw sludge for the period 1939—57 is shown in Table I. These data reveal no obvious change in grease content which would account for the heavy buildup. It is generally acknowledged that automatic washing machines, detergents, and garbage grinders came into rather widespread use at that time, but whether or not one or a combination of these items is connected with the buildup problem remains to be determined.

Cleaning Methods

In 1948, the affected lines were broken and cleaned with a knife and cable machine. The job was messy and required many man-hours of labor. In 1950, the District bought an 8-in. hydraulically operated cleaning tool (Figure 1).‡ The machine was passed through portions of the 8-in. lines and the greasy scrapings were caught in an old filter cloth. From there the material was placed in garbage cans and hauled away. This method, too, was costly and messy but a clean pipe resulted. In 1952, a device was made for easier insertion of the cleaning tool.

During the next two years both 6-in. lines were replaced with 8-in. pipes and changes were made to the 8-in. lines which connect the pumps to the concentration tanks. Among the latter changes was the repiping of the discharge end of the line to permit over-the-top delivery to the concentration tanks. The cleaning tool was captured in a slotted box, the sludge falling into the tanks (Figure 2). With this arrangement a faster, cleaner job was done.

In 1954, for the first time, it was necessary to clean the 6-in. sludge suction lines that come from the settling tanks and the 12-in. dewatering lines frequently used for sludge withdrawals. The lines were broken and cleaned with a knife and cable ma-

TABLE I.—Grease Content of Dry Weather Raw Sludge

Year	Number of Analyses	Avg Grease Content (per cent)
1939	7	19.1
1940	23	16.7
1941	23	14.3
1942	5	11.7
1944	18	17.9
1949	8	19.5
1950	15	21.1
1951	27	20.5
1952	34	21.7
1953	32	20.5
1954	52	19.2
1955	47	18.2
1956	36	18.9
1957	11	17.5

* In part from the transcript, 31st Annual Meeting, Federation of Sewage and Industrial Wastes Assns.; Detroit, Mich.; Oct. 6–9, 1958.

† Panel Leader.

‡ Flexoscraper, manufactured by Jos. G. Pollard Co., Inc., New Hyde Park, N. Y.

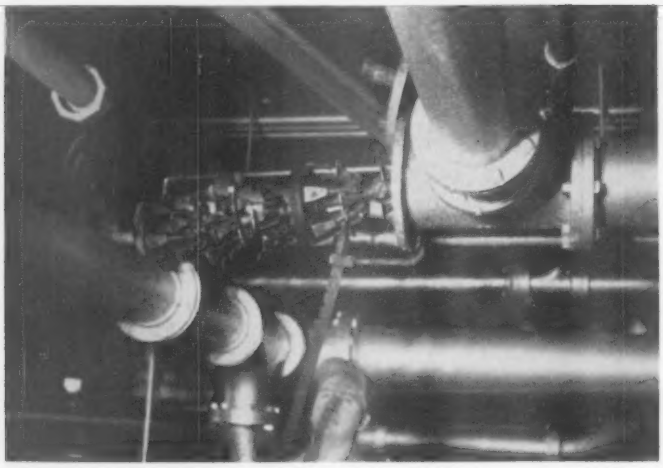

FIGURE 1.—Insertion of 8-in. cleaning tool in sludge discharge line.

chine. Again, the job was costly and messy. This same year, a 200-gpm booster pump (120 psi) was installed on the water supply to the hydraulically operated cleaning tool.

In 1955, a 6-in., a 12-in., and another 8-in. cleaning tool were purchased. In addition, changes were made at the outlets of the 8-in. lines on top of the concentration tanks to capture the tools in a safer manner. These changes brought about further cost reductions and eliminated the mess heretofore associated with the job. In 1956, changes were made to the six 6-in. sludge suction lines, each 150 to 180 ft long, and to the two 12-in. dewatering lines, each 170 ft long. A new 6-in. plant effluent line (70 psi) was installed in each pipe galley and the 6-in. suction headers to the eight sludge pumps were increased to 10-in.

FIGURE 2.—Recovery of 8-in. cleaning tool. Cleanings drop into top of sludge concentration tanks.

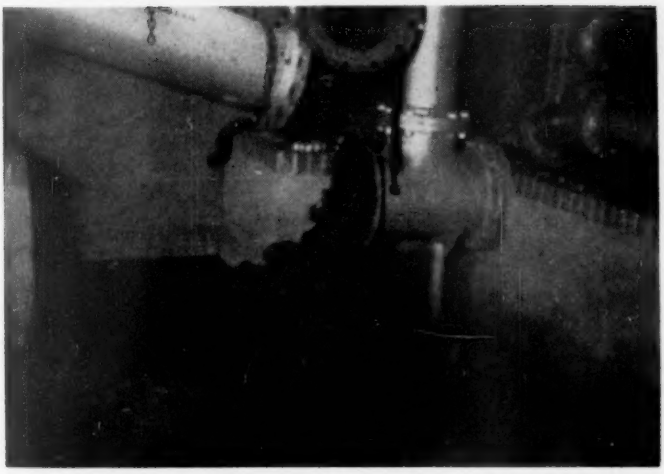

FIGURE 3.—Discharge of cleanings into brick enclosures.

In cleaning these lines, the sludge, water, and cleaning tool were captured in wooden enclosures. The resulting liquid was pumped or flushed out but to do this required a great deal of time.

In 1958, two brick enclosures were built in the pump and blower building basement to capture the sludge, water, and cleaning tools from the 12-in. lines (Figure 3). A 4-in. suction line from the brick structure is connected to the displacement pumps. High pressure hoses are used for cleaning and diluting. A metal sludge buggy is used to catch sludge and cleaning tools from the 6-in. suction lines (Figure 4). It is provided with a 4-in. valved outlet. A 4-in. hose is connected to a suction line and the buggy is emptied with one of the regular sludge pumps. Cleaning of these lines now requires few man-hours and practically no mess results.

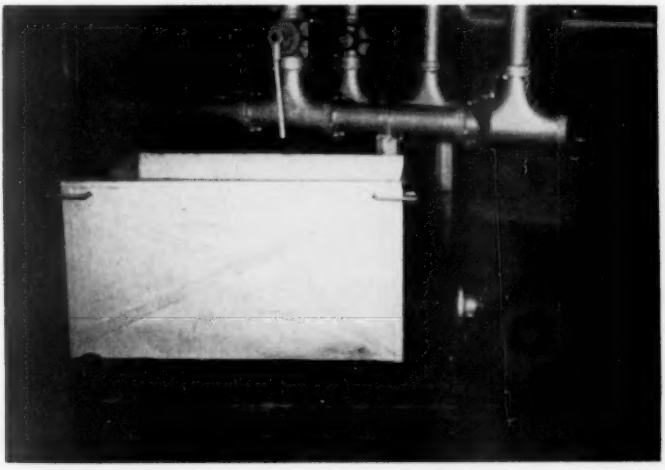

FIGURE 4.—Sludge buggy for capturing cleanings and cleaning tool.

It is still necessary to use the knife and cable machine on certain bends close to the pumps and on the pipes in the settling tank sludge sumps, but the 1,220 ft of 8-in., 340 ft of 12-in., and 960 ft of 6-in. sludge lines are cleaned with hydraulically operated cleaning tools on a routine basis. Some lines are cleaned every two weeks.

II. SLUDGE PIPE CLEANING AT DETROIT, MICHIGAN

By Fred H. Burley

Engineer of Sewage Treatment, Detroit, Mich.

Something more than coincidence seems to be involved in sludge line depositions. In Detroit, the plant was operated for about fifteen years before plugged sludge lines became a serious matter. As suggested in the preceding paper, changes in sewage characteristics may be the cause of this trouble. In Detroit, detergents are suspected but little more than a suspicion can be offered in way of an explanation.

Grease deposits build up to the point where only a trickle of sludge can be moved, even when the pumps operate at their highest speed. The sludge itself may be very heavy in the sedimentation tanks, but at the point of delivery in the filter room it is almost like water. Faced with this problem, it was decided that flushing of the lines should be tried.

Two 12-in. lines are connected to the sludge pump header. One line is directed to the sumps in the filter building. The other is routed to the digester. If necessary, sludge can be pumped through the digester control house to the filter building. First, a tee and valve were installed near the mid-points of the line between the sedimentation tanks and the filter building and the line between the sedimentation tanks and the digester. The mid-point locations selected were convenient to the interceptor, so that the flushings could be removed easily.

Next, blowoffs were installed at the ends of the sludge lines. These blowoffs consisted of a connection between the end of the sludge lines and the inlet end of the sedimentation tanks. This afforded an easy means of getting rid of the sludge that was removed from the lines.

The sludge pumps were used at their maximum capacity in scouring lines. Later, it was found that cleaning was greatly improved when warm supernatant or partially digested sludge was introduced into the lines. When the normal head in the digester is inadequate for flushing purposes, the plunger and centrifugal pumps in the digester control house are used to force the supernatant through the lines.

As in Minneapolis–Saint Paul, cleaning is done about every two weeks. If cleaning is delayed by as little as one week, sludge transfer capacities are seriously decreased.

III. SPARE PARTS AND SPARE UNITS

By C. E. Irving

Superintendent, Bureau of Sewage Treatment, Schenectady, N. Y.

Many papers and discussions have been given on subjects dealing with sewage treatment plant operation and maintenance, but few have dealt with the items probably most responsible for the continuous operation of plants, namely, spare parts and spare units.

Sewage treatment has come a long

way from the days when most of the few parts needed could be fabricated at the treatment plant shop. Today, sewage treatment is highly mechanized and spare parts and units must be available if treatment is to be continuous. Bypass is no longer the byword.

In 1950, when Schenectady broke ground for a new sewage treatment plant, spare parts and units were already receiving consideration. During construction, the availability of spare units was determined. If failure of single units would likely cause interrupted operation, a duplicate was provided.

Just having spare units in the proper place is not the whole answer to this problem. If an adequate supply of spare parts for all critical units is not on hand, the operator or superintendent has been derelict in his duty. Of course, it is easier to say, "Open the bypass to the river until we can get the necessary parts."

As the construction of the Schenectady plant progressed, inventory was taken on all units having parts that might cause a shutdown. It was enlightening to discover the number of spare parts and equipment that are necessary to keep a sewage plant operating efficiently After the inventory was completed, it was realized that all of the needed parts could not be purchased at one time, so a plan was worked out with the purchasing agent whereby each year a certain number could be added. Now, a complete stock is on hand.

The question asked on numerous occasions is—"Why carry such an extensive stock of spare parts?" Well, no operator or plant superintendent can forecast the time of day or night when a breakdown will occur and the delivery time for some replacement parts is as long as three or four months. With an adequate supply of spare parts, there is no interruption in operation and no unnecessary anxiety on the part of the operators. A complete maintenance record is kept on each unit in the plant, listing the date, part used, its cost, and the cost of installation. In this way, the weak spots in the plant can be discovered and corrective action may be taken. Also, from these records a maintenance budget can be prepared.

Floor Discussion

Van P. Enloe, Superintendent, Clayton Sewage Treatment Plant, Atlanta, Ga.:—The first system of sludge line cleaning used in Atlanta was patterned after a method used at Coney Island. This system consisted of flushing with a mixture of compressed air and water. We had quite a bit of success eight or ten years ago. But, as was pointed out by the panelists, sludge and grease seem to build up in the lines faster in these latter years.

As a result, we have had to go to something else, so we purchased a flexible pipe cleaner. This cleaner is hydraulically operated. It was used on the 6-in. line which connects the clarifiers to the digesters. This line is 630 ft long.

It took quite a bit of time to get it through the line the first time. Several times we were afraid that it would stop. We ran it through a second time and then cleaned a line to another digester in the same way. In order to make cleaning simpler, we made a cross connection at the digesters which permitted us to run the pipe cleaner from the sludge pumps to the digester, then around a 90-degree elbow and across to the other sludge line and back to the clarifier. We are doing this every month.

From the Floor:—I have a question I would like to direct at Mr. Burley concerning warm supernatant injected into sludge lines. In our plant we have been fortunate in not having to clean our sludge lines. We may be on

the verge of it but we have not done it as yet. We have only a primary plant and we do not have warm supernatant.

Is it your opinion, Mr. Burley, that warm water might be used for the same purpose?

Mr. Burley:—I think that warm water would serve the same purpose very well. It is mostly a matter of economics.

At Detroit, we do not have the large amount of warm water that would be required to clean our 12-in. sludge lines. The amount of supernatant used might run to 50,000 or 100,000 gal.

L. T. Haggerty, Sewage Treatment Engineer, Dayton, Ohio:—I am going to stick my neck out a little bit. We had the same problem with deposits until two years ago. We found that by increasing velocities we eliminated the problem.

Our longest line measures 250 ft and we introduce air to increase the velocity to the telescoping valves. At that point we put in a smaller line than the original design called for. We now have a 6-in. line and move about 25,000 cu ft of 5 per cent sludge in 7½ hr. I think the velocity figures out to be just under 5 fps.

Joseph B. Hanlon, Superintendent, Sewage Treatment, Metropolitan District Commission, Boston, Mass.:—We have experienced all of the problems mentioned today—broken pumps, broken pipe lines—all caused by the difficulties of sludge pumping. Our sludge line is about one mile long; it is a loop of two runs of about one-half mile each.

The original design provided for a flexible pipe line cleaner and an access chamber. The characteristics of the sludge were such that the cleaner compacted the sludge into plugs as long as 80 to 100 ft. These plugs had to be rodded out.

The pipe line was buried from 6 to 8 ft deep. There were only two access manholes and steam could not be used because there wasn't any way to remove the condensate. After six or seven months of continuous difficulty, every man in the plant was assigned to the project. Trouble was not limited to the sludge lines. It was a matter of cleaning the pumps and the valves in the lines, as well as the long lines. We tried supernatant from the digesters which helped when we could get enough of it, but when you use supernatant you interfere with the normal operation of the plant. The plant is shut down and sludge accumulates in the sedimentation tanks.

Finally, we designed and bought a 5,000,000-Btu heat exchanger and an 800-gpm pump of the type used for moving 25 lb paper stock. We bring the temperature up to 160 to 170°F and clean the lines and pumps in about 4 hr.

Mr. Sager:—Well, I think it's very obvious from the discussion already presented that pipe lines in which trouble is likely to occur shouldn't be buried. This isn't always possible of course, but a real effort should be made to build as much accessibility as possible into the piping layout.

There is another problem in design which should be recognized. I still don't know why an access opening isn't put at the lower level of a digester. Even with a separate sewerage system, grit will collect in the digester. Some fellows say that it takes four months to clean one out.

A. Paul Troemper, District Engineer, Springfield Sanitary District, Springfield, Ill.:—In a new digester, which is presently under construction, we do have a hatch opening in the side. We are going to be able to clean it a lot easier than the old tanks. I certainly feel that a side opening in a digester is well worth whatever money you put into it.

The "Ten State Standards" for design, which are being fairly well accepted, require that the digester vol-

ume be calculated on the basis of the sludge standing on a 30-degree slope with the horizontal. I think that in many plants a lot of grit will be mixed with the sludge and it will stand at steeper slopes. You may get up to 45 or even 60 degrees.

Some of our older digesters haven't been cleaned in a number of years and I would estimate that we have lost better than a quarter of the capacity of these tanks.

From the Floor:—What type of grit chamber do you have?

Mr. Troemper:—We have the conventional, velocity-type grit chamber. But there are times when you get a carry-over of grit, especially after a heavy storm.

I don't believe that any available grit removal device is 100 per cent efficient.

From the Floor:—We have one plant with an open digester that is building up a terrific amount of scum. The sun beats down on it all day long and the scum is as dry and hard as it can be. Is there anything you can do to break it up?

Murray B. McKinnie, Superintendent, Sewage Treatment Plant, Santa Rosa, Calif.:—At another place in California we built a new plant and had to clean out a septic tank. The tank had about 15 ft of scum in it. We used fire hoses to break it up. It was a rather slow job but it did work.

From the Floor:—I have heard recently that sodium hexametaphosphate sprinkled on scum sometimes helps to soften it up. I wonder if there is any more information available?

Charles E. Hughes, Superintendent, Sanitary District of Decatur, Decatur, Ill.:—Recently, we used sodium hexaphosphate for a digester. We dissolved it and then used an ejector to work it out against the scum area. It was entirely unsuccessful.

Mr. Sager:—Does anyone else have something to say on the matter of scum?

William H. Higgins, Engineer and Manager, Sewage Treatment Plant, Trenton, N. J.:—We use aluminum sulfate in connection with our scum trouble. We mix alum with our raw sludge and pump it to the digesters. We have floating covers but we still have scum. At one time we had around seven or eight feet of scum. When we started out with alum too much was added and foaming took place. After that experience we cut down the dosage and now have good control.

Mr. Troemper:—In cleaning our digesters, we found scum anywhere from 2 to 4 ft thick. We broke it up with compressed air by sticking an air hose through it. The dispersed scum appears to settle well.

Mr. Sager:—Does anyone have a problem with vacuum filters?

From the Floor:—We tried several types of filter media and had exceptional success with polyethylene. Cotton flannel was good for 200 to 300 hours, but polyethylene produced good results for 5,000 to 6,000 hours. When the polyethylene medium was changed it was usually to make repairs under the cloth, not because the cloth needed it.

Mr. Irving:—We have done quite a bit of experimentation with the various cloths. We dewater digested primary sludge.

Originally, we used cotton flannel and got about 125 hours of service. We tried washing it and found it didn't pay. Then we tried polyethylene and had poor results.

We finally hit upon Dynel. The manufacturer worked with us very extensively and it was found that a cloth with a very strong nap produced excellent results. We have an average yield of about 10 to 11 psf/hr from our filters in Schenectady. Our cloth runs now range from 500 to 700 hours.

We steam clean our cloth when it becomes clogged. We use a detergent in our cleaner. The first cleaning is

followed by a cleaning with boiling water. This procedure more than doubles the life of the cloth.

From the Floor:—Do you clean the cloth on the filter?

Mr. Irving:—Yes.

From the Floor:—We use a hydrochloric acid solution for cleaning. We put the solution in the filter pan and rotate the drum. By reversing the rotation of the drum, not only the cloth, but the decking behind the cloth is cleaned. Since we have been able to cut down our lime dosage, we haven't had to clean cloths as often. We clean them after 1,000 to 3,000 hours of use.

From the Floor:—We filter a digested mixture of primary and activated sludge. The coagulant used is ferric chloride, to which a very small amount of Separan is added. Separan is expensive, but you use very little.

We have experimented for years with different types of filter media. We have used cotton cloth, Dynel, Orlon, and nylon, but always went back to wool.

About a year or two ago, we read that Chicago was getting phenomenal results with a Dacron cloth. We bought one Dacron blanket, which cost about 30 per cent more than the wool. Our experience with wool has been about 900 hours of operation, which we thought was pretty good. The first Dacron blanket got torn and was destroyed after 8,600 hours, which was rather astonishing.

Now, all of our filters are equipped with Dacron cloths. The price has come down and it is almost the same price as wool. Of course, it lasts ten times as long as wool.

From the Floor:—How do you clean large electric motors—50 to 200 hp? What method do you use?

Mr. Burley:—Well, this is a good time for me to get in a plug for safety, which is closely associated with maintenance.

As a first step, we remove the motor and tag the safety switch. Following cleaning by blowing, the motor receives a solvent cleaning. At one time, carbon tetrachloride was used extensively for cleaning motors and grease removal in general. It is no longer used because of its toxic fumes. Instead, a safer substitute, of which there are many, is used.

The bearings should always be cleaned and repacked. I think it is important that only certain men, preferably the electrical maintenance crew, touch the bearings of electric motors. Nothing ruins electric motors more often than too much grease.

The insulation and windings should be inspected and defects should be corrected. This is followed by recoating.

Mr. Higgins:—We are constantly patching our roof. We can't seem to keep our copings tight.

I was wondering if anybody has an idea on how to keep copings leakproof.

Virgil Anderson, Architectural Engineer, City Water Board, Detroit, Mich.:—This coping problem is, of course, a serious one, not only on digesters, but on any building. We attempted to solve it by using an aluminum coping and copper flashing.

The sewage treatment plant buildings have been in use now for 18 years and we have had no trouble with this kind of coping.

From the Floor:—We have quite a bit of trouble with a rotary-type gas meter. Do you send these meters back to the factory or do you repair them yourself?

We have tried to repair them but never have a whole lot of success.

W. E. Ross, Superintendent, Sanitary District and Sewage Treatment Plant, Richmond, Ind.:—We find that it is necessary to change the oil in the

bearing housing about once every three or four weeks. If we do that, we cut our maintenance way down. Longer intervals between oil changes cause a great deal of trouble.

We happen to treat garbage with our sewage and find that we get a carry-over of condensate in the meters. This causes quite a bit of trouble, but we have been able to eliminate most of it by using special oils and changing them quite often.

One time we were told to use castor oil, but we found it was entirely too viscous. So, we went back to the old oil and changed it more often.

If you take the meter apart, you have to be careful in replacing the parts. The parts have very small clearances.

OPERATOR TRAINING AND CERTIFICATION IN NEW YORK*

By Meredith H. Thompson

Acting Director, Bureau of Environmental Sanitation, New York State Department of Health, Albany, N. Y.

The certification of water and sewage treatment plant operators is done with but one objective in mind—to make reasonably certain that treatment facilities will be operated efficiently and effectively. This objective can be fulfilled only by the employment of qualified, competent operating personnel on a continuing basis. The method for accomplishment may vary from state to state but the basic objective remains the same. In many instances, operator groups have been the motivating force in seeing that training and certification procedures are established and carried out. The Federation of Sewage and Industrial Wastes Associations and the American Water Works Association, together with their many affiliates, and the state health departments have offered guidance, support, and coordination in the development of certification programs.

The need for qualified, competent operators of water and sewage treatment plants is more pronounced today than ever before. The ever increasing use and reuse of water by municipalities and industries, the discharge of new types of wastes, and the increasing use of water resources for recreational, agricultural, and other pursuits, combine to make treatment problems much more complicated.

It is the responsibility of each state and community to develop a workable plan which will produce and keep on the job the competent and qualified operators needed to cope with today's and tomorrow's water and waste treatment problems.

New York's Program

Classification

Many states have programs for the certification of operating personnel which are working satisfactorily. In New York, persons wishing to be appointed or employed as operators must have certain educational and experience qualifications. The details of qualification certification are covered in Chapter XI of the New York State Sanitary Code. This Chapter specifies that no person shall be employed or

* Presented at the 9th Joint Conference, Florida Section, American Water Works Assn. and Florida Sewage and Industrial Wastes Assn.; Oct. 19–22, 1958; Miami Beach, Fla.

appointed as an operator or assistant or shift operator unless he possesses the qualifications prescribed for such position at the time of employment. Six grades are established for both water and sewage treatment plant operators. The grades are: I-A, I-B, II-A, II-B, III-A, and III-B. These grades are based on the degree of treatment rendered by the specific plant and the population served. Actually, the plants themselves are placed in either the I, II, or III category. An "A" operator can operate any plant in the State requiring an operator in his grade or a lower grade. For instance, an operator with qualifications approved as Grade I-A can operate any plant in the State. On the other hand, a Grade II operator can operate any Grade II or III plant but not a Grade I plant. A Grade III operator can operate only a Grade III plant. An operator approved in the "B" category can operate only a specifically designated plant as it existed on the date of application. Furthermore, the "B" operator is not allowed to operate any other plant or the same plant if major changes are made.

As indicated previously, the Grade I-A operator is qualified to operate any plant in the State. He must have a bachelor's degree in a related field of engineering or in chemistry. He must have not less than one year of experience. The other grades require less education and varying amounts of experience. Some of the grade qualifications require satisfactory completion of an appropriate course of instruction.

It is necessary that all plant operators in responsible charge possess the qualifications established by the Sanitary Code for the plant they are to operate. It does not mean that they are covered by civil service nor does it mean that they cannot be discharged. In many instances, however, the position is covered by local civil service. Where this is the case, qualifications must be certified before the civil service examination can be taken. The Municipal Service Division of the New York State Department of Civil Service works in cooperation with the local civil service boards and the New York State Department of Health to have these positions placed on a civil service status. This is a very satisfactory arrangement. If the position is not covered by civil service status the officials may replace a qualified and competent operator. However, such replacement must be with a person meeting the required qualifications. So, even under these conditions, the requirement of certification is a deterrent to frequent turnovers.

Under certain conditions a qualified operator may not be available. The Public Health Council may grant a waiver of qualifications in order to give the applicant an opportunity to obtain, within a specified time, the necessary training and experience. These persons are generally required to attend an appropriate, approved course of instruction.

Training

In addition to basic courses of instruction, it is necessary to provide operators with an opportunity to stay abreast of progress in their particular field and to study for advancement to the next higher grade. Accordingly, schools covering Grades II and III for both water and sewage treatment plant operators are conducted periodically at various points throughout the State. The schools vary in length from three to five days for Grade III schools to two weeks for Grade II schools. No course has been established for Grade I-A because of the educational requirement contained in the Sanitary Code.

The curriculum of the schools is designed to meet the needs of the specific

operators. The responsibility for conducting Grade III schools rests with the five regional engineers of the State Department of Health. They determine through the local health units the number of operators or persons who wish to or must attend a Grade III school. The date for the school is decided, a place to conduct it is selected, and arrangements are made for competent instructors. The selection of instructors who can teach and who also know the practical aspects of plant operation is often a most difficult job. Since these schools are conducted by five different engineers and by different instructors, a great variation in subject matter presented could undoubtedly follow without a standard curriculum and manual. To avoid this problem a manual is prepared which, in addition to its classroom value, provides each operator with reference material.

At the completion of the course, a written examination is given. The student must attend all appropriate sessions of the course to be eligible to take the examination. If the applicant passes the examination and has sufficient experience, he may apply to the Public Health Council for approval of his qualifications. If approved, he is issued a certificate by the State Department of Health setting forth the grade in which he is qualified. No fee is charged for the certificate or for attendance at the course.

Grade II water and sewage treatment plant operator schools are conducted at universities by contract with the State Department of Health. At least four widely separated universities conduct such courses. Here again, a standard curriculum and manual are used. The only fee charged for the course is the university laboratory fee of approximately $25 or $30.

Before determining the courses to be taught at the various schools past experiences are evaluated and conferences are held with operators and university and Health Department personnel.

The scheduling of the schools is varied to meet the need of the operators in a particular area. In one area Grade III schools may be conducted on three to five consecutive days while in another area they may be conducted on the basis of one day a week for three to five consecutive weeks. The one-day-a-week plan permits the operator to be absent from his plant a minimum of time and involves minimum cost. The Grade II schools are generally conducted on a basis of five days a week for two consecutive weeks. One university conducts the course on the basis of one day a week for 30 consecutive weeks.

Conclusions

Experience with compulsory certification in New York has proved to be satisfactory. It has not solved all the problems but it has resulted in a greater number of competent operators and a reduction in the number of changes in operating personnel. It requires that the municipality employ persons with specific qualifications.

It is the writer's opinion that a voluntary certification program will not accomplish its intended objective since it is usually the operator who does all the volunteering. The second party—the municipality—must also be an active participant.

EFFECTS OF CHROMIUM WASTES ON ACTIVATED SLUDGE

By S. A. Stankey

Superintendent, Sewage Treatment Plant, Fairfield, Conn.

This discussion describes some of the effects of chromium wastes on the activated sludge process at Fairfield, Conn., from the time these wastes entered the plant until they were finally removed from the raw sewage flow. Also, it describes how the chromium wastes were eliminated from the sewage and what was done to bring the activated sludge and sludge digestion processes back to normal.

The effectiveness of the activated sludge process depends in a large measure on environmental factors. This aquatic environment must be kept in balance at all times. It must be supplied with optimum amounts of suspended solids and dissolved oxygen. It must be maintained at an optimum pH and adequate contact time must be provided for the micro-organisms present. Any radical changes in the composition of the wastes to be treated tend to upset the balance.

It has long been recognized that metals, such as copper and chromium, contained in industrial wastes may cause trouble in sewage treatment. They are toxic to the micro-organisms on which all biological treatment processes depend.

Normal Conditions

The Fairfield sewage treatment plant is of the conventional activated-sludge type, designed to treat 4 mgd of sanitary sewage. At present, there are, in addition to the sanitary connections, about 20 industries using the system. A few of these industries have objectionable wastes, mainly acids, which require pretreatment. Wastes discharged to the city system must have a pH within the range of 5.0 to 9.0.

During the five years prior to March 1957, operations at Fairfield were very satisfactory. During this period occasional slugs of acid were received at the plant, caused mainly by mechanical or human failures at industrial pretreatment facilities. When acids appeared in the sewage their source was immediately traced and steps were taken to remove or neutralize them.

Chromium Wastes

Observations

These occasional, limited discharges of acids or caustics were of minor consequence in comparison with the conditions that occurred during March and April of 1957.

One morning during the first week of March it was found that the sewage in all of the open treatment units was colored a greenish yellow. At first it was believed that a batch of dye had been dumped by some industry. However, instead of clearing up after 24 hr the sewage in the treatment units was an even darker green.

The effects on the activated sludge process were marked. The floc, instead of having sharply defined edges, became very fine and pin-point in appearance. The final effluent, instead of being crystal clear, became turbid and activated sludge began to flow over the weirs. The pH of the final effluent dropped from a normal value of 6.9 to 6.0. The dissolved oxygen in the mixed liquor was very hard to measure because the color of the sewage interfered with the Winkler method. Thus, the air requirements of the process were a guess. The BOD removal dropped from 95 to 70 per cent and the suspended solids removal dropped from 96 to 78 per cent. Gradually, the pH of the digesting sludge dropped

from 6.9 to 6.4. The total alkalinity also dropped from 2,200 to 1,400 mg/l, with a slight decrease noted in gas production. During this period the pH of the raw sewage fluctuated but in general it remained very low. The lowest value observed was 1.3.

Source

The adverse operating conditions described above continued until the cause was discovered and corrected. It was felt certain that this troublesome condition was caused by a toxic industrial waste, hence, an attempt was made to find the source. With the dark green coloring present in the sewage this was very easily accomplished. The source turned out to be a new chromium-plating company that had moved into town and had connected its industrial waste discharge to the sewer system without notification. This company had started 24 hr/day operations, discharging their chromium rinse waters without any pretreatment. Their rate of discharge was 192,000 gpd which was approximately 10 per cent of the total flow to the plant at the time.

Samples were taken and sent to the laboratory of the Connecticut State Department of Health for analysis. The results of these tests showed that 28 mg/l of hexavalent chromium was present in the sewer line adjacent to the plating plant and that there was still 7 mg/l of hexavalent chromium present in the primary settling tank effluent even after dilution with a flow of 2 mgd of sewage.

The State Department of Health advised that this quantity of chromium was excessive for the proper operation of the plant. They recommended that Fairfield take immediate steps to have the plating company reduce the chromium discharge to safe levels.

Elimination of the Problem

The owners of the factory explained that they had been displaced by the new Connecticut Turnpike and had moved to Fairfield from a large, nearby city where they had been located for years. In their previous location they were able to discharge their industrial wastes without any pretreatment. At their former location, the city operated a primary treatment plant only and had no sludge digestion facilities. Raw sludge was dewatered on vacuum filters. The differences between the methods of sewage treatment in use at each city were explained as well as the need for pretreatment at Fairfield.

Later, a meeting was held with all interested officials in attendance. At this meeting, suggestions were made to the company on possible ways of remedying the condition. The company owners were very cooperative. One of the methods suggested, and the least costly to initiate, was to build drip trays on which the plated castings would be allowed to drain. The drainage, as well as the rinse water used on the castings, was to be returned to the chromium solution tanks. In the old method the castings were washed immediately and all drainage entered the sewer. In the new method rinsing was to be done with a fine water spray. The pH was to be kept within the prescribed range by adding the necessary neutralizing chemicals to the waste discharge.

The company immediately had trays made and started using the new system. Results were very gratifying both to the plating company and to the Town of Fairfield. The discharge of chromium was drastically reduced, and the addition of neutralizing chemicals, when needed, corrected the very acid conditions previously noted.

Since the in-plant changes to the plating process have been made the company is realizing a very substantial saving in chromium costs. More than 50 per cent of chromium formerly wasted is now recovered. The fine-spray rinse has reduced water consumption drastically. Water use has

dropped from 192,000 to 72,000 gpd, a reduction of nearly 60 per cent.

Although the chromium discharge from this source has not been completely eliminated, the small amount that still enters the sewer does not noticeably affect the treatment process.

During the period of upset operating conditions, a slurry of hydrated lime was added to the mixed liquor in the aeration tanks to maintain a normal pH. Also during this period and for a few days after the condition was corrected, a total of 5,000 lb of lime was added to the raw sludge entering the primary digester. At the end of the 10-day period of lime addition the pH of the digester's contents was raised from 6.4 to 7.0 and the total alkalinity was raised from 1,400 to 2,200 mg/l; the latter figure is normal for the Fairfield plant.

The difficulties at Fairfield are not intended to imply that a secondary treatment plant cannot treat industrial wastes. To the contrary, industrial wastes are treated in the Fairfield activated sludge plant, but there are limitations on the amount and character of the wastes that can be handled.

TIPS AND QUIPS

Bon Voyage

Getting the world's largest mobile offshore platform to sea took some tricky maneuvering to duck under the Golden Gate Bridge and then jump over a sand bar at the mouth of the bay.

With its four "legs" towering more than 200 ft above water, the 4,500 ton "George F. Ferris" headed toward Los Angeles, where it will soon begin the spectacular operation of "walking" the ocean floor to assemble the largest, heaviest, longest, and deepest sewer pipe ever pieced together under water.

The unique platform played leap frog through San Francisco Bay to get its 275-ft high legs over and under obstacles. It was probably the only time in the history of the Golden Gate Bridge that a marine craft had to duck its head to get under the main span.

It took about eight days for the platform to reach the Los Angeles area. When ready, the "George F. Ferris" will jack down its legs to the ocean floor and begin laying six miles of 12-ft diameter sewer pipe in water up to 200 ft deep.

The $20 million sewer pipe job is being handled by Hyperion Constructors, a joint venture of six well-known construction firms.

Getting the mammoth rig out of San Francisco Bay was tricky. Its four 275-ft high legs had to be jacked to full height to permit the rig to be towed through shallow water from a dock in Richmond, where the legs were erected. As soon as it entered deep water in the bay, the "George F. Ferris" quickly lowered its legs 57 ft to clear the 232-ft high bridge span. Then, after passing underneath, its legs were rapidly raised to clear the offshore sand bar. Once at sea, the platform made its final leg adjustment. The 25-story-high stilts were lowered until 37½ feet dragged underneath the hull, providing adequate navigational stability. Legs can be jacked up or down at a speed of about 40 ft per hour.

Weather and tide controlled the sailing date of the "George F. Ferris." The departure was postponed until weather experts predicted at least a week of calm sea for the tow to Los Angeles. High tide was required in the Bay to get the rig away from its dock in Richmond and over the offshore sand bar. A strong

FIGURE 2.—The "George F. Ferris" sails under the Golden Gate.

current entering the Gate was also needed to slow the rig enough to provide time to raise the legs in the relatively short stretch between bridge and sand bar.

The "George F. Ferris" will lower 600-ton assembled sections of pipe to the ocean floor, connect them with previously laid sections, and then backfill around them with a cradle of gravel. After each 192-ft long pipe section is laid, the rig will "walk" ahead by first jacking down its platform on the legs until the entire unit floats. Then it will winch itself ahead to the next pipe position, lowers its legs, and lift itself above the reach of waves to repeat the sequence.

The self-elevating principle has been used to install offshore oil drilling platforms and also the first Texas Tower radar station in the Atlantic Ocean. But the technique has never been attempted at such a great depth of water, or on a device requiring so many separate jacking operations. To lay the 32,000 ft of offshore pipe, the rig will be jacked up and down at least 170 times. Pipe alignment, jointing, and backfilling will be monitored by underwater television.

Indicators of Good Sludge Digestion *

Look for the following signs:

1. The pH of the digester contents should be close to 7.0 or slightly higher.
2. The volatile acids content should be less than 300 mg/l.
3. The total alkalinity should be greater than 2,000 mg/l.
4. The digester gas should contain less than 36 per cent carbon dioxide.

* Newsletter of the California Sewage and Industrial Wastes Assn. (Dec. 1958).

News and Notes

Of Persons and Activities in the Wastewater Field

Dr. Willem Rudolfs died recently in his native Netherlands. He was known widely for his outstanding work in the wastewater field for many years at Rutgers University, from where he had been retired since 1952. Dr. Rudolfs was elected to Honorary Membership in the Federation in 1945 and was an Emerson Award winner in 1944.

The Federation is greatly indebted to Dr. Rudolfs for many contributions. Among the outstanding of these was his long and faithful tenure as Chairman of the Research Committee.

Harry E. Jordan will retire September 1 after nearly 23 years as Secretary of the American Water Works Association. The water utility business has been fortunate in receiving 56 years of his service.

Arthur J. Scanlon, chief of sewage disposal operations of the New York City Department of Public Works, died recently.

Dr. J. Carrell Morris has recently been promoted to the rank of Professor of Sanitary Engineering at Harvard University.

Dr. James C. Lamb III has been appointed Associate Professor of Sanitary Engineering in the Department of Sanitary Engineering at the University of North Carolina. For the past several years he has been with the American Cyanamid Company as a Sanitary Engineer at the Boundbrook, New Jersey plant.

Gordon E. Mau is now employed by the Ralph Parsons Company and is on an assignment in Dacca, East Pakistan.

Walter A. Sperry recently retired as Superintendent of the Aurora, Illinois, Sanitary District after 28 years of service. He won the Gascoigne Medal in 1952, the Bedell Award in 1949, and the Hatfield Award in 1950.

Glen H. Abplanalp, Alvin M. Mock, and **Stanley H. Sutton** have been admitted as Partners in the consulting engineering firm of Havens and Emerson; and **George D. Simpson, Carl E. Lesher, Jr.,** and **Sol Koplowitz** have been advanced to Associates.

W. H. (Pete) Wisely, Executive Secretary of ASCE and formerly Executive Secretary-Editor of the Federation, has recently been appointed a lecturer in Sanitary Engineering at the University of Illinois. In this capacity he will deliver several lectures each year.

Infilco Incorporated, Tucson, Arizona, has announced the acquisition of the Gale Separator Company of Bloomfield, N. J.

Fozi M. Cahaly has been appointed one of five Vice-Presidents of the engineering firm of Fay, Spofford & Thorndike, Inc., Boston, Massachusetts.

A. D. Caster, Principal Sewage Disposal Engineer of Cincinnati, Ohio, was elected Vice-President of the Cincinnati Section of the American Society of Civil Engineers for the 1959–60 term.

D. M. McDowell has been named Director of Engineering for the **Roots-Connersville Blower Division** of Dresser Industries, Incorporated.

Henry J. Miles has joined the staff of the University of Arizona as Professor of Civil Engineering in charge of hydraulics and fluid mechanics.

John J. Priest, Chief Chemist for the Halifax Paper Company, Roanoke Rapids, N. C., died recently.

George E. Glover has been named Manager of the Industrial Waste Department of the Cochrane Corporation, Philadelphia, Pa.

George A. Horlacher has been appointed a regional engineer–utilities in the Cleveland, Ohio, area by B-I-F Industries, Inc.

J. S. Newman has been named Executive Vice-President and General Manager of Josam Manufacturing Company, Michigan City, Indiana.

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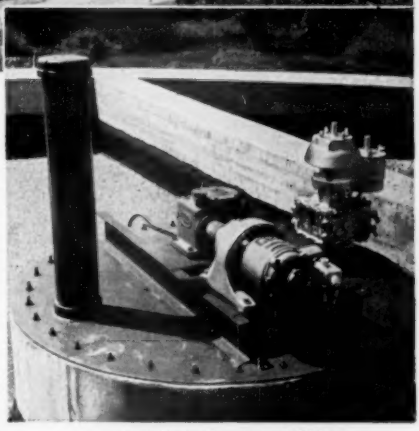

"VAREC" Fig. No. 5800C
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Proceedings of Member Associations

MISSOURI WATER AND SEWERAGE CONFERENCE

The Annual Joint Meeting of the Missouri Water and Sewerage Conference and the Missouri Section of the American Water Works Association was held at the Hotel Governor, Jefferson City, Mo., Sept. 28–30, 1958. Registration totaled 296.

The technical program was a good one and effective use was made of panel discussions. Among the papers of particular interest to sewage works and industrial waste treatment personnel were:

"New Wage Law of Missouri," by June R. Rose, Chairman, Industrial Commission, Jefferson City, Mo.

"Pertinent Aspects of the Water Pollution Law," by Jack K. Smith, Executive Secretary, Water Pollution Board, Jefferson City, Mo.

"Panel Discussion: Licensing Program for Sewage Works Operators."

"Panel Discussion: Sewer Maintenance."

"Pump Maintenance and Cavitation," by Leo Galvin, Jr., Manager, Pump Department, Fairbanks, Morse and Co., St. Louis, Mo.

"Sewage Oxidation Basin Studies at Fayette," by Dr. Joe K. Neal, Biologist, USPHS, Kansas City, Mo.

The Bedell Award for outstanding personal service to the Conference was presented to Prof. Lindon J. Murphy *in absentia*. Prof. Harold Babbitt accepted for Prof. Murphy.

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Missouri Water and Sewerage Conference for 1958–59 were the following:

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Vice-Chairman: Lawrence Martin, Independence.
Secretary-Treasurer: Warren Kramer, Jefferson City.

WARREN KRAMER
Secretary-Treasurer

NEBRASKA SEWAGE AND INDUSTRIAL WASTES ASSOCIATION

The 7th Annual Meeting of the Nebraska Sewage and Industrial Wastes Association was held at the Lincoln Hotel, Lincoln, Nebr., Nov. 6–7, 1958. The total registration was 68.

The technical program covered the sewage and industrial waste field very well. Among the subjects discussed were: A report on the use of electri-

(*Continued on page 160a*)

PROFESSIONAL OPPORTUNITY

The Department of Sanitary Engineering of the District of Columbia is accepting applications for the positions of Sewage Treatment Plant Shift Superintendents.

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cal power and electrical hazards in Nebraska sewage treatment plants; vacuum filters; the effect of industrial wastes on small sewage treatment plants; and the status of the two-day operators' short course.

At the annual dinner Federation Secretary, Ralph Fuhrman, presented the Hatfield Award to Loren Brannen, Operator, Sewage Treatment Plant, Central City, Nebr., in recognition of outstanding plant operation. The Bedell Award for extraordinary service to the Association went to V. J. Lechtenberg, Chicago Pump Co., Omaha, Nebr.

New officers for the year 1958–59 are:

President: Harold Hoskins, Lincoln.
Vice-President: Loren Brannen, Central City.
Director: T. A. Fillipi, Lincoln.
Secretary-Treasurer: V. J. Lechtenberg, Omaha.

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Equipment and Supply Lines

Millipore Filters—A 16-page brochure is available describing basic characteristics, analytical techniques, laboratory apparatus, field apparatus, and process applications of the millipore filters.—Millipore Filter Corp., 36 Pleasant St., Watertown 72, Mass.

Pumps—An 8-page bulletin describes a new line of general purpose, end suction pumps.—Aurora Pump Div., The New York Air Brake Co., Aurora, Ill.

Valves—Rubber or Saran lined check valves are described for use in the pulp and paper and chemical industries where protection afforded by these liners is desirable for wastes handling.—Bulletin 11-W, Golden-Anderson Valve Specialty Co., 1248 Ridge Ave., Pittsburgh 33, Pa.

Cast Iron Joints—A brochure describes "Fastite," a double-sealing, single gasket type joint for cast iron pipe.—American Cast Iron Pipe Co., Birmingham 2, Ala.

Level Control—A level control for the detection of liquid, solid, and slurry high or low point is available. Control is obtained from utilization of an electrical output signal that varies with the amount of immersion of a vibrating paddle.—Automation Products, Inc., 3030 Max Roy St., Houston 24, Texas.

Flocculation—Bulletin 315–51 describes flocculation equipment available from Chain Belt Co., Milwaukee 1, Wis.

Valve Lubrication—A new high-pressure hand gun for lubrication of plug valves is offered (Bulletin V-608) from Meter and Valve Division, Rockwell Manufacturing Co., 400 N. Lexington Ave., Pittsburgh 8, Pa.

Hose Nipples—For low-volume wastes causing corrosion problems, stainless steel hose nipples are available from Band-it Co., 4777 Dahlia St., Denver, Colo.

Flow Rate Alarms—Fluid flow rate alarms for signalling or simple control functions, either magnetic or electronic types, are available for use with rotameters.—Bulletin 165, Brooks Rotameter Co., Lansdale, Pa.

Solids Classification—A revised catalog covering classifiers, hydroseparators, washers, and heavy media separators is available.—Bulletin 39-C, Hardinge Co., Inc., York, Pa.

Salt Separation—An electro dialyser, called "Webcell," designed for pilot plant, laboratory, or instruction is available and provides data on the separation of soluble salts from solution by using ion selective membranes in an electrical field.—Dept. 101, Brosites Machine Co., 50 Church St., New York 7, N. Y.

Laboratory Fume Hoods—A newly designed exhaust hood utilizes improved design which allows smooth admission of air, bypass unit, and other features.—Fisher Scientific Co., 419 Fisher Bldg., Pittsburgh 19, Pa.

Control Valves—Three-way control valves, both single- and double-seated designs, for mixing or diverting service are described in Specification S810-16 from Minneapolis-Honeywell Regulator Co., Valve Division, Fort Washington, Pa.

Positive Blowers—Increased capacity ratings are announced for type AF rotary positive blowers and type XA rotary positive gas pumps, made possible by design refinements allowing higher operating speeds.—Roots-Connersville Blower, Connersville, Ind.

Instrumentation—An 8-page bulletin describes how telemeters enable users to observe and record the operation of widely scattered meters at a central location from any distance.—Bulletin 230-P4, Builders-Providence, Inc., 345 Harris Ave., Providence 1, R. I.

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(Continued through page 169a)

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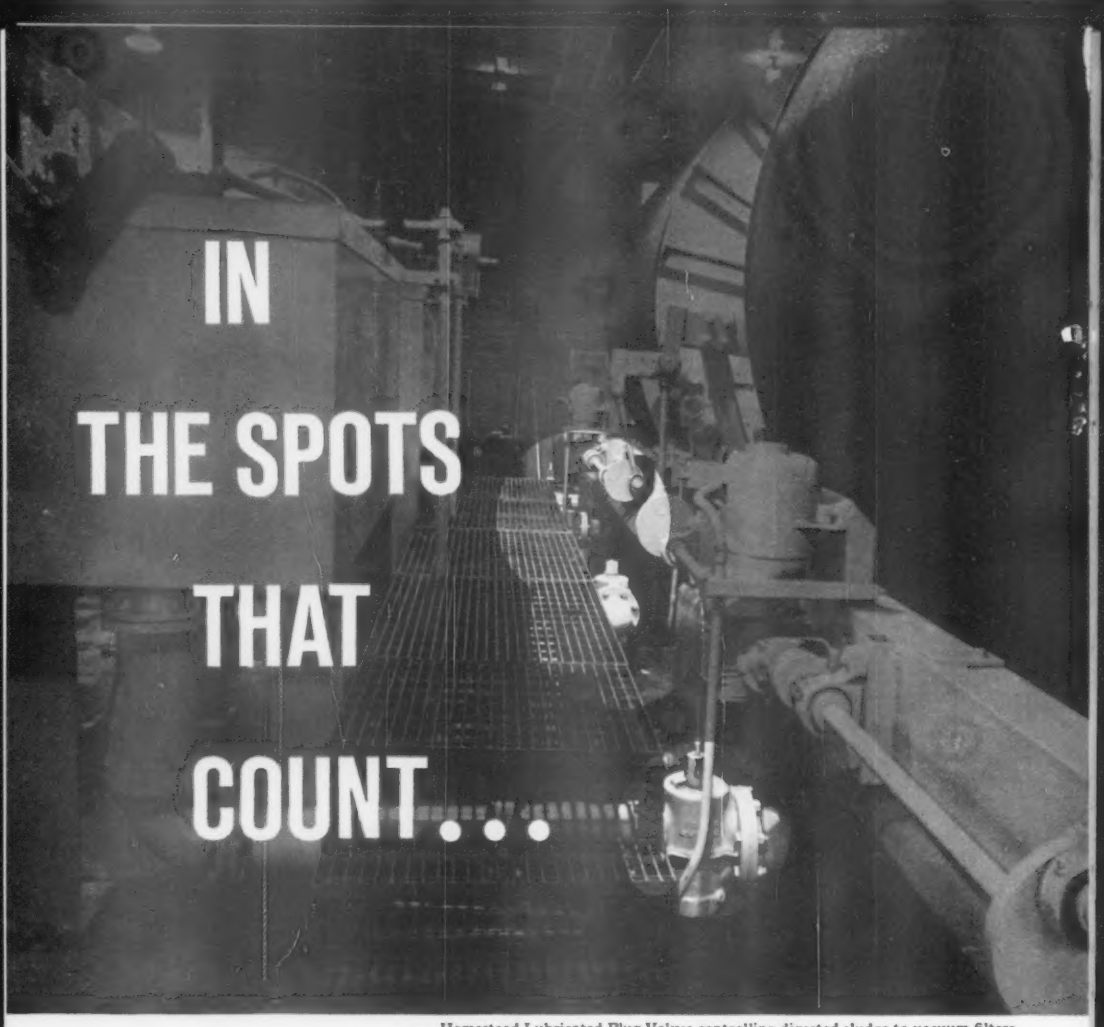

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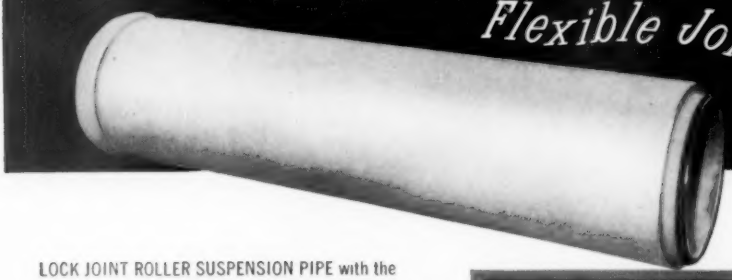

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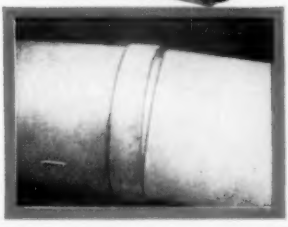

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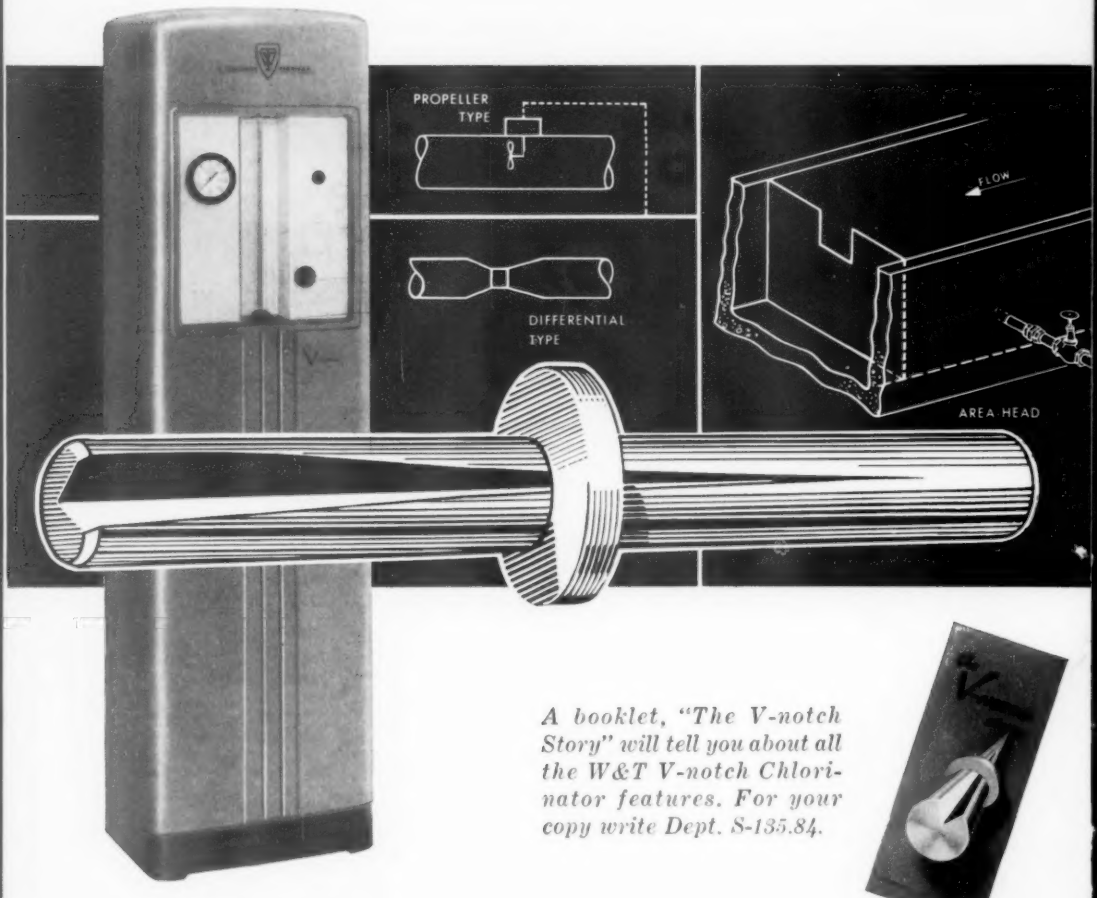

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